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MEMORANDUM

PERFORMANCE OF TYPICAL REAR-STAGE AXIAL-FLOW
COMPRESSOR ROTOR BLADE ROW AT THREE
DIFFERENT BLADE SETTING ANGLES

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PERFORMANCE OF TYPICAL REAR-STAGE AXIAL-FLOW COMPRESSOR ROTOR

BLADE ROW AT THREE DIFFERENT BLADE SETTING ANGLES*

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SUMMARY

A comparison of the performance of a single-stage rotor run at three different blade setting angles is presented. The rotor was of a design typical for a last stage of a multistage compressor. At each setting angle, the rotor blade row was operated from 53 to 100 percent of equivalent maximum speed (850 ft/sec tip speed) at constant inlet pressure. Hot-wire anemometry was used to observe rotating-stall and surge patterns in time unsteady flow.

Results indicated that an increase in peak pressure ratio and an increase in maximum equivalent weight flow were obtained at each speed investigated when the blade setting angle was decreased. An increase in peak efficiency was achieved with decrease in blade setting angle for part of the range of speeds investigated. However, the peak efficiencies for the three blade setting angles were approximately the same at the maximum speed investigated. The flow ranges for all three configurations were about the same at minimum speed and decreased at almost the same rate when the rotative speed was increased through part of the range of speeds investigated. At maximum speed, the flow range for the smallest setting angle was considerably less than the flow range for the other two configurations.

A decrease in efficiency and flow range for the smallest blade setting angle at maximum speed can be attributed primarily to a Mach number effect. In addition, because of the difference in projected axial chord lengths at the casing wall, some effect on performance could be expected from the change in three-dimensional flow occurring at the tip.

Rotating-stall characteristics for the two smaller blade setting angles were essentially the same. Only surge could be detected for the largest blade setting angle in the unstable-flow region of operation.

E-117

CT-1

INTRODUCTION

In the design of a high-pressure-ratio, multistage, axial-flow compressor for gas turbine application, low axial velocities in the exit stages are desirable in order to avoid the use of undesirably short blades in the exit stages and to keep to a minimum the amount of axial diffusion required between the compressor and the combustors. However, low axial velocities result in high stagger angles, which are usually avoided because of possible penalties, particularly in flow range.

The object of this research program was to determine the effect of stagger angle on the performance and flow range of a rotor designed as typical of a rear stage of a multistage compressor. A typical blade row was designed for a given set of inlet conditions and resulted in a blade setting angle of 58.7° at the blade tip. Throughout the range of setting angles investigated, no changes in hub-tip radius ratio, blade solidity, blade camber, or blade twist were made - as would be done if a blade row were to be designed for each setting angle and the same inlet equivalent flow. The rotor was operated over a range of wheel speeds and weight flows for blade setting angles of 38.7° , 58.7° , and 68.7° corresponding to stagger angles of 45° , 65° , and 75° , respectively. The low and high stagger angles compare with high and low axial velocities, respectively. At each blade setting angle, five speeds from 53 to 100 percent of maximum speed (450, 550, 650, 750, and 850 ft/sec) were investigated. Performance data were obtained for a range of weight flows from the minimum obtainable with the throttling system to the flow corresponding to a pressure ratio near 1 for each speed investigated.

This report presents and compares the over-all performance, stall characteristics, and blade-element parameters at three blade setting angles over the speed range previously mentioned.

ROTOR DESIGN

The rotor used in these tests was the same as the short-chord rotor discussed in reference 1. A passage with constant hub and tip diameter was specified in order to minimize any radial-flow effects due to curvature. No inlet whirl was used at the inlet to the rotor, and the rotor was designed for a relative inlet-air angle of 65° at the tip. The blade sections consisted of circular-arc suction and pressure surfaces. Button bases were used to facilitate blade angle resetting. A photograph of the rotor wheel with the blades set at 58.7° at the tip is shown in figure 1. The pertinent design details for the rotor blades are presented in table I.

APPARATUS AND INSTRUMENTATION

A schematic diagram of the test facility used for this investigation is shown in figure 2 and is described in detail in reference 2. The over-all performance and rotating-stall and surge instrumentation was identical to that used for the investigation reported in reference 1.

PROCEDURE

At setting angles of 38.7° , 58.7° , and 68.7° at the tip, the rotor was tested at equivalent tip speeds of 450, 550, 650, 750, and 850 feet per second. A sketch of the blade tip sections at the three setting angles tested is given in figure 3. At each speed, performance data were obtained for a flow range between the minimum flow obtainable with the throttling system and a flow corresponding to a pressure ratio near 1. The absolute inlet pressure was equal to 25 inches of mercury for all tests.

Total and static pressures, total temperature, and flow-angle data were taken at stations 1 (before rotor) and 2 (after rotor) for three radial positions, which were 0.2, 0.7, and 1.2 inches from the outer casing (85.7, 50.0, and 14.3 percent of passage height, respectively).

During stall operation, hot-wire anemometers were used to examine surge and stall flow characteristics over the entire passage. Inaudible high-frequency surge was distinguished from rotating stall by the inability to detect any phase shift in the signals of two hot wires displaced circumferentially at a given axial station (ref. 3). The changes in flow characteristics that occurred when rotating stall or surge was encountered or when their frequencies changed were observed as flow was increased and also as flow was decreased.

RESULTS AND DISCUSSION

The performance data obtained from testing a rotor at three different blade setting angles (38.7° , 58.7° , and 68.7° at the tip) are presented. For each configuration, the over-all performance and the surge and stall characteristics are discussed. Blade-element data are presented for the three blade setting angles investigated, and some comparisons of various parameters are made. This is followed by a comparison of the over-all performance for the configurations investigated. (All symbols are defined in the appendix.)

Performance with Setting Angle of 38.7° at Tip

Over-all performance. - The performance data obtained for this rotor row are given in figure 4 as mass-averaged adiabatic temperature-rise

E-117

CT-1 back

efficiency and mass-averaged total-pressure ratio against equivalent weight flow. The maximum pressure ratio of 1.27 was attained at a weight flow of 15.45 pounds per second. The efficiency at this point was 86.5 percent. The peak efficiency for this speed was 89.6 percent at a weight flow of about 16.2 pounds per second and a pressure ratio of 1.25. The weight-flow range at the highest speed (850 ft/sec) was 1.73 pounds; the flow ranges at the four lower speeds were greater than this by 53 to 223 percent. This represents a weight-flow variation from 2.7 to 5.6 pounds per second.

Stall and surge performance. - Except for the highest speed tested, no abrupt change in performance was noted as the flow was decreased below that of the incipient-stall point. For the two lowest speeds (450 and 550 ft/sec), a rotating stall of three zones was observed as the incipient-stall point was passed. Further decrease in flow resulted in a high-frequency surge for the lowest speed, followed by a rotating stall of two zones. The number of stall zones was determined by the method described in reference 3. At the next-to-lowest speed, the rotating-stall configuration changed to one and then two zones as the flow was reduced to the minimum obtainable. At the three highest speeds (650, 750, and 850 ft/sec), a high-frequency surge was encountered as flow was decreased. Further decrease resulted in rotating stall. It is of interest to note that, at the lowest flow possible, rotating stall was present at each speed.

Performance with Setting Angle of 58.7° at Tip

Over-all performance. - The over-all performance is presented in figure 5 as plots of mass-averaged adiabatic temperature-rise efficiency and mass-averaged total-pressure ratio against equivalent weight flow. At the maximum tip speed, a maximum mass-averaged pressure ratio of 1.21 was achieved. The equivalent weight flow and the mass-averaged adiabatic efficiency at this point were 9.75 pounds per second and 83.3 percent, respectively.

The peak efficiency for the maximum speed was 88 percent at a pressure ratio of about 1.15 and a weight flow of 11.5 pounds per second. At this speed, the flow range from peak pressure ratio to a pressure ratio near 1 was 2.6 pounds per second. The flow range in pounds per second for all other speeds was within ± 8 percent of the flow range at maximum speed. This represents an absolute variation in flow of only ± 0.2 pound per second.

Stall and surge performance. - An abrupt change in performance at all speeds occurred when rotating stall was encountered. The magnitude of the pressure drop and decrease in efficiency is evident in figure 5.

E-111/

An initial rotating stall of one zone extending from tip to hub occurred at all speeds. As the flow was reduced, the number of zones increased to a maximum of two zones for the two highest speeds and progressively to a maximum of four zones for the other speeds. Further decrease in flow resulted in surge for all but the lowest speed. For the lowest speed, after rotating stall was encountered, it was necessary to increase the flow above that of the incipient-stall point before rotating stall was eliminated and thereby produce the characteristic of a hysteresis loop. For all other speeds, stalling and unstalling occurred at about the same weight flow.

Performance with Setting Angle of 68.7° at Tip

Over-all performance. - The mass-averaged adiabatic temperature-rise efficiency and mass-averaged total-pressure ratio against equivalent weight flow are presented in figure 6. At the maximum pressure ratio of slightly less than 1.16, the equivalent weight flow and efficiency were 6.54 pounds per second and 81.5 percent, respectively. The peak efficiency for the highest speed was 86.6 percent at a pressure ratio slightly greater than 1.15 and a weight flow of 7.2 pounds per second. At the highest speed, the flow range from a pressure ratio near 1 to the point of incipient flow fluctuation was 1.86 pounds per second. Except for the next-to-highest speed, the flow ranges for the other speeds were lower than the flow range at the top speed by 4.3 to 15 percent. The flow range at the next-to-highest speed was greater by 4 percent than the flow range at the highest speed. This represented a weight-flow variation of 1.7 to 1.9 pounds per second.

Stall and surge performance. - At all speeds except the lowest, decreasing the mass-flow rate below the incipient-stall point resulted in a high-frequency surge of about 26 cycles per second. Figure 6 shows that there was very little total-pressure drop when this high-frequency surge was encountered. Because of limitations of the system, the mass-flow rate could not be reduced sufficiently at the lowest speed to cause surge. For the tip speeds of 650 and 850 feet per second, an audible surge of about 5 or 6 cycles per second was also present.

Blade-Element Performance

The conventional blade-element performance is given in figures 7 to 14 for the three rotor settings tested. The various parameters plotted in these figures are discussed in reference 4.

The plots of inlet relative Mach number against incidence angle (fig. 7) show that, at all speeds and all radial positions, the Mach number

level is highest for the 38.7° blade setting angle and lowest for the 68.7° blade setting angle. It can also be seen from these plots that the 38.7° blade row is operating at inlet relative Mach numbers equal to or greater than 0.8 at all radial positions for the two highest speeds (except for a small portion of the operating range for the hub position at the 750 ft/sec speed).

The plots of the loss coefficient $\bar{\omega}$ against incidence angle in figure 8 show that, at every speed and radial position, the optimum incidence angle is greatest for the 38.7° blade row, followed by the 58.7° and 68.7° blade rows in that order. Chapter VI of reference 4 shows that the optimum incidence angle increases with an increase in inlet relative Mach number (the curve of ref. 4 is plotted only for Mach numbers up to 0.8). The data presented in this report are consistent with the trend indicated in the reference.

A study of all blade-element data presented in this report indicates that the major differences in performance occur at the tip for the three blade setting angles investigated. There are also some significant differences in performance at high-flow and low-flow data points at each radial position.

Comparison of Over-All Performance

Unstalled operation. - The effect of blade setting angle on compressor performance is indicated in figure 15, where various performance parameters are plotted against equivalent tip speed. This figure shows that peak mass-averaged total-pressure ratios increase with decrease in blade setting angle for any given tip speed. A peak-pressure-ratio point for the 68.7° setting angle could not be determined for the 450-foot-per-second tip speed because of system limitations. At 550 feet per second, a 4-percent increase in pressure ratio is obtained as the blade setting angle is decreased from 68.7° to 38.7° . At maximum speed, a 10-percent increase in pressure ratio is obtained for the same change in setting angle.

A significant increase in maximum weight flow with decrease in blade setting angle is evident in figure 15, where maximum weight flow is plotted against equivalent tip speed for the three configurations. At minimum speed, a 190-percent increase in maximum weight flow is obtained as the blade setting angle is decreased from 68.7° to 38.7° . At maximum speed, a 100-percent increase in maximum weight flow is obtained for the same change in setting angle.

Also plotted against equivalent tip speed in figure 15 are the mass-averaged peak adiabatic temperature-rise efficiencies for the three configurations. It is evident that greater peak efficiencies were achieved as the blade setting angle was decreased at each of the speeds investigated. The differences in peak efficiencies become less as speed is

increased beyond 650 feet per second, so that at maximum speed the efficiencies for the three blade setting angles are approximately the same. As the speed is increased from 650 feet per second to the maximum, the peak efficiencies for the 38.7° and 58.7° blade setting angles decrease 6 and 3 points, respectively, while the efficiency for the third setting angle increases 3 points.

A flow-range parameter is utilized in order to compare the compressor performances for the three configurations in the flow regime where no rotating stall or surge is present and where no total-pressure drop across the rotor is incurred. This flow-range parameter is defined as follows:

$$\text{Flow-range parameter} = \frac{\left(\frac{w_o \sqrt{\theta_o}}{\delta_o} \right)_{\bar{P}_2 \approx 1.0} - \left(\frac{w_o \sqrt{\theta_o}}{\delta_o} \right)_{\text{Incipient stall}}}{\left(\frac{w_o \sqrt{\theta_o}}{\delta_o} \right)_{\bar{P}_2 \approx 1.0}}$$

where $\left(\frac{w_o \sqrt{\theta_o}}{\delta_o} \right)_{\bar{P}_2 \approx 1.0}$ is the equivalent weight flow at the minimum pres-

sure ratio tested (very near 1.0) and $\left(\frac{w_o \sqrt{\theta_o}}{\delta_o} \right)_{\text{Incipient stall}}$ is the equivalent weight flow at the operating point just before rotating stall or surge is detected. The flow-range parameter gives the choke-free and stall-free flow range over which the compressor can operate as a percent of maximum flow. A plot of flow-range parameter against equivalent tip speed (fig. 15) indicates little difference in flow range (within 3 points) for the three configurations at speeds less than 700 feet per second. The data point for the 68.7° setting angle at 450 feet per second is omitted because a value for $\left(\frac{w_o \sqrt{\theta_o}}{\delta_o} \right)_{\text{Incipient stall}}$ was not obtained, because of system limitations. As speed is increased above 700 feet per second, the flow range for the smallest setting angle decreases more rapidly than does the flow range for the other two configurations. Thus, at maximum speed the flow range for the 38.7° setting angle is about one-half the flow range for the 58.7° and 68.7° setting angles.

An inspection of figure 15 indicates that increases in maximum pressure ratio, maximum weight flow, and peak efficiency are gained with

decrease in blade setting angle and that no penalties are incurred up to a tip speed of about 700 feet per second. This improved performance may be attributed primarily to increased work input with little change in losses as blade setting angle is decreased. However, as tip speed is increased above 700 feet per second, it becomes obvious that some phenomenon is causing a decrease in efficiency for the 58.7° and 38.7° setting angles and a significant decrease in flow range for the 38.7° setting angle. Mass-averaged inlet relative Mach numbers for the flow ranges investigated are arithmetically averaged and plotted in figure 15 against equivalent tip speed. The data point for the 68.7° setting angle at 450 feet per second is omitted because of the reason mentioned previously. This plot shows that Mach numbers greater than 0.8 are present for the 38.7° setting angle at speeds greater than 700 feet per second. Thus, it can be surmised that the smallest setting angle is operating in the region where compressibility effects are causing an increase in losses and a decrease in flow range. Because of the high work input for the 38.7° setting angle, the efficiency is still high, and therefore the Mach number effects on efficiency can be tolerated. The decrease in flow range for this rotor at speeds above 700 feet per second appears to be caused primarily by severe choking limits due to high inlet Mach numbers, as is evident from the plot of maximum equivalent weight flow in figure 15. Inasmuch as the last stage of a multistage compressor is operating nearer its stall point when the compressor is operating at high speeds, and nearer choking conditions at low speeds, this apparent change of range may have little effect on applicability to multistage compressor design.

Rotating stall and surge. - The pertinent facts concerning the stall characteristics for the three rotor settings are listed in table II. Presented in the table are the surge frequencies and number of rotating-stall zones detected, as well as the order in which they were encountered. The absolute propagation rate used in this table is defined as the ratio of the absolute rotative speed (in radians/sec) of one zone divided by the rotor rotative speed. The observations are numbered in sequence for unique operating points. These numbered points do not necessarily correspond to the solid or half-solid symbols presented in figures 4, 5, and 6, which are shown only to indicate the trend in rotor performance as the flow rate is varied after rotating stall or surge is encountered.

Table II and figures 4, 5, and 6 show that there is no obvious trend in the stall and surge performance as the rotor blade row is changed from a setting angle of 68.7° at the tip to one of 38.7° . Therefore, it was not possible to predict whether a particular rotor at a given speed would encounter abrupt or progressive rotating stall or high (inaudible) or low (audible) frequency surge as the flow is decreased.

SUMMARY OF RESULTS

The performance obtained by testing a single-stage rotor at three different blade setting angles (38.7° , 58.7° , and 68.7° at the tip) has been compared. The rotor was of a design typical for a last stage of a multistage compressor. The following results were obtained:

1. At all speeds, the 38.7° setting blade row had the highest peak pressure ratio, and the 68.7° setting row the lowest.

2. At all speeds, the 38.7° setting row had the highest maximum weight flow, and the 68.7° setting row the lowest.

3. At all speeds, the 38.7° setting blade row had the highest peak adiabatic efficiency, and the 68.7° setting row the lowest.

4. The flow ranges, as defined by the difference in equivalent weight flows at minimum pressure ratio tested (near 1.0) and at the operating point just before surge or rotating stall was detected, divided by the equivalent weight flow at the minimum pressure ratio, were about the same at minimum speed for all three blade setting angles and decreased at about the same rate until the 650-foot-per-second speed was exceeded. The smallest (38.7°) setting angle then showed a more rapid decrease in flow range, so that at maximum speed its flow range was about one-half the flow ranges for the other two setting angles. This apparent change in flow range is primarily due to severe choking limits and therefore may have little effect on multistage performance, as the last stage would be operating nearer stall conditions during high compressor speeds.

5. The 38.7° setting blade row encountered rotating stall at the two lower speeds and surge at the three higher speeds, with no abrupt pressure drop except at the highest speed; rotating stall was encountered at the lowest flow points at all speeds. The 58.7° setting blade row exhibited abrupt rotating stall at all speeds; audible and inaudible surge were also detected at all but the lowest speed. The 68.7° setting blade row had inaudible surge at all speeds except the lowest, with no pressure drop.

CONCLUDING REMARKS

Low axial velocities in the exit stages of multistage axial-flow compressors are desirable in that they permit the use of lower hub-tip ratios and avoid the undesirability of short blades; they also decrease the amount of axial diffusion required between the compressor and combustor to obtain good combustor performance. In spite of these

advantages, the use of increased blade setting angles (higher stagger angles) is often avoided because of the possible decreases in flow-range capabilities with increased blade setting angles. The data reported herein indicate that, for the type of velocity diagram studied, no penalty in flow range is incurred over a range of blade setting angles that correspond to stagger angles from 45° to 75° . The changes in flow that do occur with change in angle are primarily at the choke-flow end of the stage performance at high speeds and, therefore, are not near the operating point of the compressor.

Lewis Research Center

National Aeronautics and Space Administration
Cleveland, Ohio, September 2, 1958

APPENDIX - SYMBOLS

| | |
|----------------|---|
| D | diffusion factor |
| H | total enthalpy |
| i | incidence angle, angle between inlet-air direction and tangent to blade mean camber line at leading edge, deg |
| M | Mach number |
| P | total pressure |
| U | rotor blade speed, ft/sec |
| V | air velocity, ft/sec |
| w | weight-flow rate, lb/sec |
| β | air angle, angle between air velocity and axial direction, deg |
| $\Delta\beta$ | air-turning angle, $\beta_1 - \beta_2$, deg |
| δ | ratio of total pressure to NACA standard sea-level pressure of 29.92 in. Hg abs |
| δ° | deviation angle, angle between outlet-air direction and tangent to blade mean camber line at trailing edge, deg |
| η | adiabatic temperature-rise efficiency |
| θ | ratio of total temperature to NACA standard sea-level temperature of 518.7° R |
| σ | blade solidity, ratio of chord to spacing |
| $\bar{\omega}$ | total-pressure-loss coefficient |

Subscripts:

| | |
|---|---------------------------------|
| h | hub |
| m | mean |
| o | stagnation conditions (orifice) |
| t | tip |

z axial direction

1 inlet station

2 outlet station

Superscripts:

' relative to rotor

- mass or radial average

REFERENCES

1. Kussoy, Marvin I., and Bachkin, Daniel: Comparison of Performance of Two Aerodynamically Similar 14-Inch-Diameter Single-Stage Compressor Rotors of Different Chord Length. NACA RM E57I03, 1957.
2. Graham, Robert W., and Prian, Vasily D.: Experimental and Theoretical Investigation of Rotating-Stall Characteristics of Single-Stage Axial-Flow Compressor with Hub-Tip Ratio of 0.76. NACA RM E53I09, 1953.
3. Huppert, Merle C.: Preliminary Investigation of Flow Fluctuations During Surge and Blade Row Stall in Axial-Flow Compressors. NACA RM E52E28, 1952.
4. Members of the Compressor and Turbine Research Division: Aerodynamic Design of Axial-Flow Compressors. Vol. II. NACA RM E56B03a, 1956.

TABLE I. - ROTOR DESIGN GEOMETRY

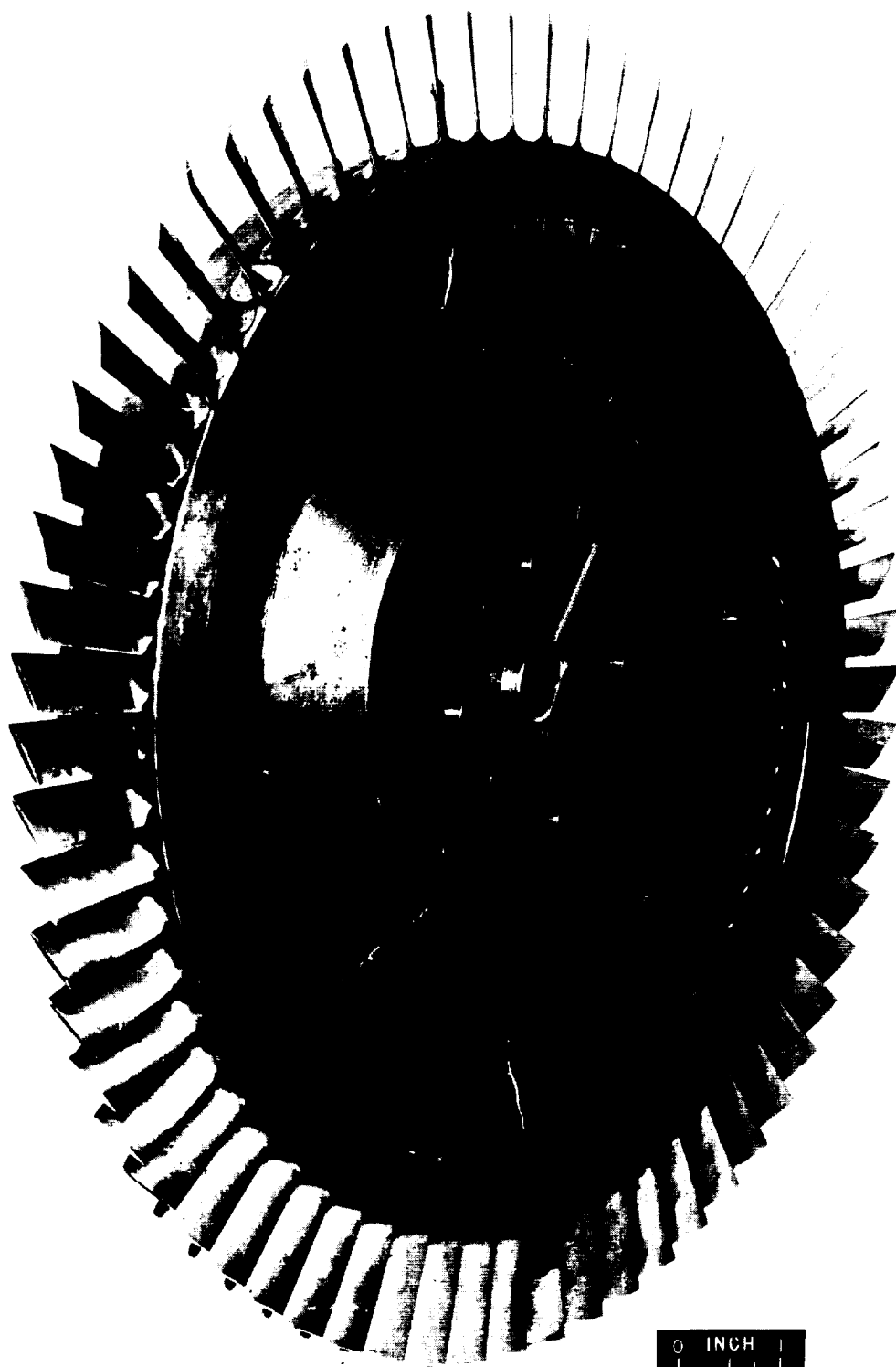
| | | | |
|---|-------|--|------|
| Tip radius, in. | 7.00 | Relative inlet-air angle, β'_1 , deg | 60.7 |
| Hub radius, in. | 5.60 | $r = 5.6"$ | 62.6 |
| Passage height, in. | 1.40 | $r = 6.3"$ | 65.0 |
| Hub-tip ratio | .8 | $r = 7.0"$ | |
| Chord, in. | .67 | Incidence angle, i , deg | 7.6 |
| Aspect ratio | 2.09 | $r = 5.6"$ | 5.9 |
| Solidity, σ_t | 1.005 | $r = 6.3"$ | 3.4 |
| Number of blades | 66 | $r = 7.0"$ | |
| Tip thickness-to-chord ratio | .10 | Deviation angle, δ° , deg | 5.3 |
| Hub thickness-to-chord ratio | .12 | $r = 5.6"$ | 3.8 |
| Tip speed, $U_t/\sqrt{\theta}$, ft/sec | 850 | $r = 6.3"$ | 2.8 |
| Leading- and trailing-edge radii, in. | .010 | Air-turning angle, $\Delta\beta$, deg | 10.8 |
| Fillet radius, in. | .125 | $r = 7.0"$ | 9.8 |
| | | Approx. blade solidity, σ | 8.5 |
| | | $r = 5.6"$ | 1.3 |
| | | $r = 6.3"$ | 1.1 |
| | | $r = 7.0"$ | 1.0 |

TABLE II. - STALL HISTORIES OF BLADE ROW AT THREE SETTING ANGLES

| Equivalent speed, $U_t / \sqrt{\theta}$, ft/sec | Absolute propagation rate | Surge or stall frequency, cps | Observation ¹ (as flow is decreased) |
|--|---|--|--|
| Setting, 38.7° at tip | | | |
| 450 | | 205 44.5 113 | 1. Rotating stall, 3 zones 2. Surge 3. Rotating stall, 2 zones |
| 550 | | 340 70 140 | 1. Rotating stall, 3 zones 2. Rotating stall, 1 zone 3. Rotating stall, 2 zones |
| 650 | | 46 82 175 | 1. Surge 2. Rotating stall, 1 zone 3. Rotating stall, 2 zones |
| 750 | | 46.5 27.9 92 205 | 1. Surge 2. Surge 3. Intermittent rotating stall, 1 zone 4. Rotating stall, 2 zones |
| 850 | | 44 26.1 99 234 | 1. Surge 2. Surge 3. Rotating stall 4. Rotating stall } Insufficient data available to determine number of zones |
| Setting, 58.7° at tip | | | |
| 450 | 0.595 .595 .595 .595 | 75 75 75 75 | 1. Rotating stall, 1 zone 2. Rotating stall, 2 zones 3. Rotating stall, 3 zones 4. Rotating stall, 4 zones |
| 550 | 0.604 .604 .604 .604 ----- .604 ----- ----- ----- | 93 93 93 93 4 93 60 120 60 | 1. Rotating stall, 1 zone 2. Rotating stall, 2 zones 3. Rotating stall, 3 zones 4. (a) Rotating stall, 4 zones (b) Intermittent audible surge 5. (a) Rotating stall, 4 zones (b) Surge, frequency I (c) Surge, frequency II 6. Surge |
| 650 | 0.578 .578 .578 .578 ----- ----- ----- ----- | 105 105 105 105 78 4 78 4 78 | 1. Rotating stall, 1 zone 2. Rotating stall, 2 zones 3. Rotating stall, 3 zones 4. (a) Rotating stall, 4 zones (b) Surge (c) Audible surge 5. (a) Surge (b) Audible surge 6. Surge |
| 750 | 0.594 .594 .594 ----- ----- ----- ----- | 124 124 124 26 87.5 4 87.5 | 1. Rotating stall, 1 zone 2. Rotating stall, 2 zones 3. (a) Rotating stall, 2 zones (b) Surge 4. (a) Surge (b) Audible intermittent surge 5. Surge |
| 850 | 0.568 .568 ----- ----- ----- ----- | 135 135 26 96 4 98 | 1. Rotating stall, 1 zone 2. Rotating stall, 2 zones 3. Surge 4. (a) Surge (b) Audible intermittent surge 5. Surge |
| Setting, 68.7° at tip | | | |
| 450 | | | Rotating stall or surge was not obtained at this speed because of system limitations |
| 550 | | 25 | 1. Surge |
| 650 | | 25 25 8 25 | 1. Surge 2. (a) Surge, frequency I (b) Surge, frequency II (audible) 3. Surge |
| 750 | | 25 | 1. Surge |
| 850 | | 25 6 25 6 6 25 | 1. Surge 2. Surge (audible) 3. Surge 4. Surge (audible) 5. (a) Surge, frequency I (audible) (b) Surge, frequency II |

¹Observations are numbered in sequence for unique operating points; conditions labeled (a), (b), and (c) indicate more or less simultaneous observations.

E-117



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Figure 1. - Rotor wheel with blades set at 58.7° at tip.

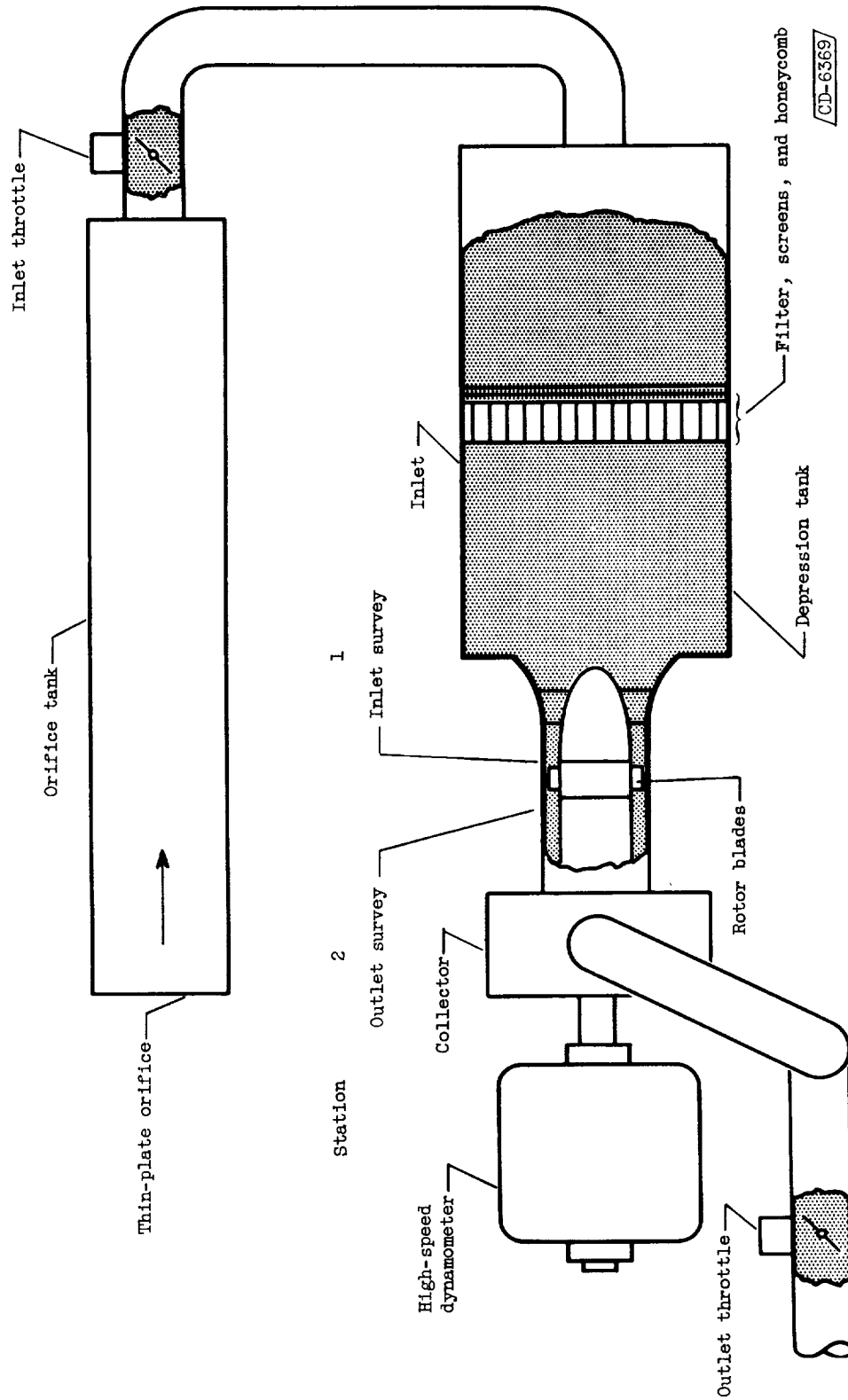
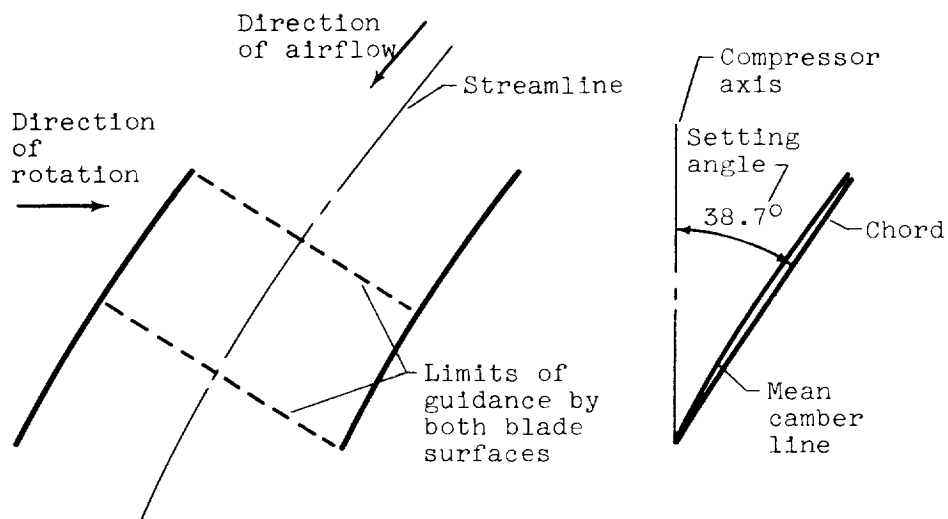


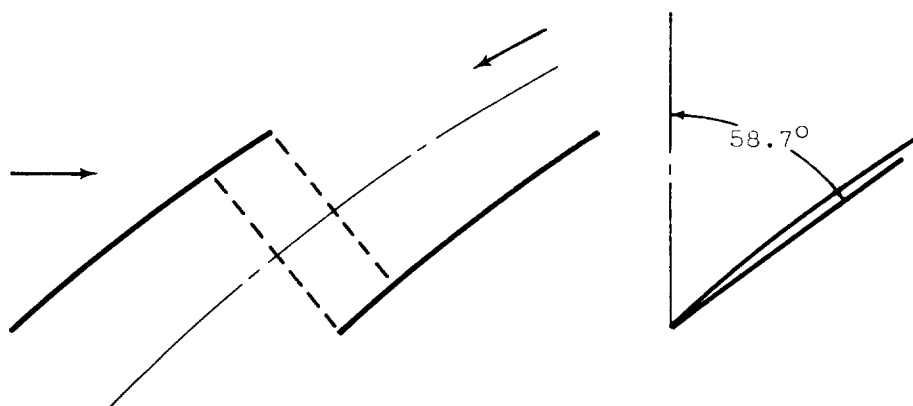
Figure 2. - Compressor blades.

E-117

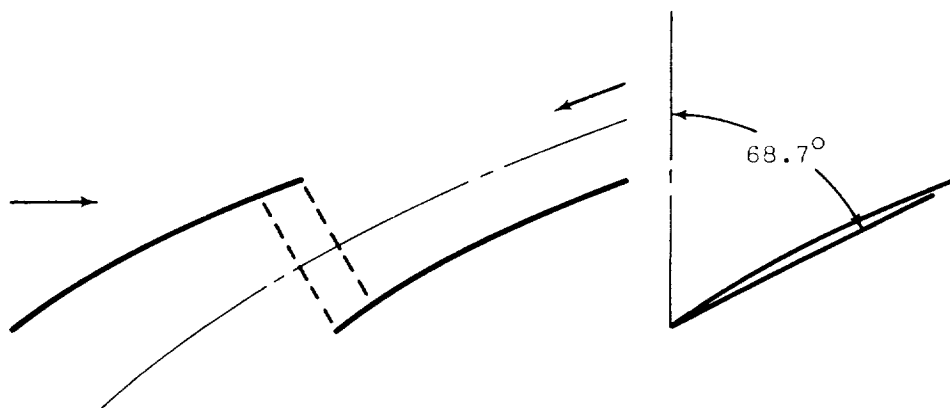
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(a) Blade row setting, 38.7°.



(b) Blade row setting, 58.7°.



(c) Blade row setting, 68.7°.

Figure 3. - Sketch of blade tip sections at three different setting angles.

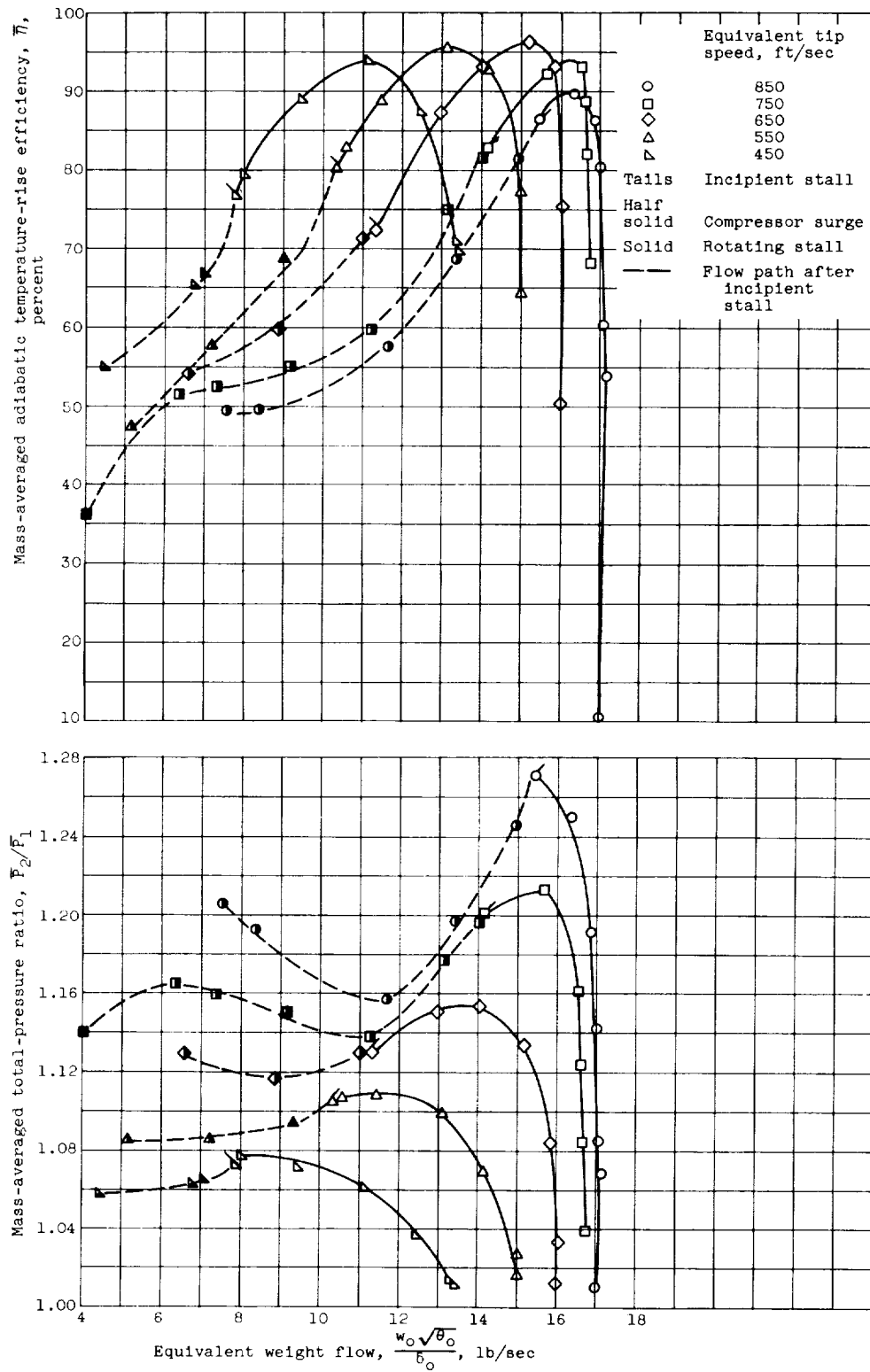


Figure 4. - Over-all performance of 38.7° setting blade row. Inlet pressure, 25 inches of mercury absolute.

E-117

CT-3 back

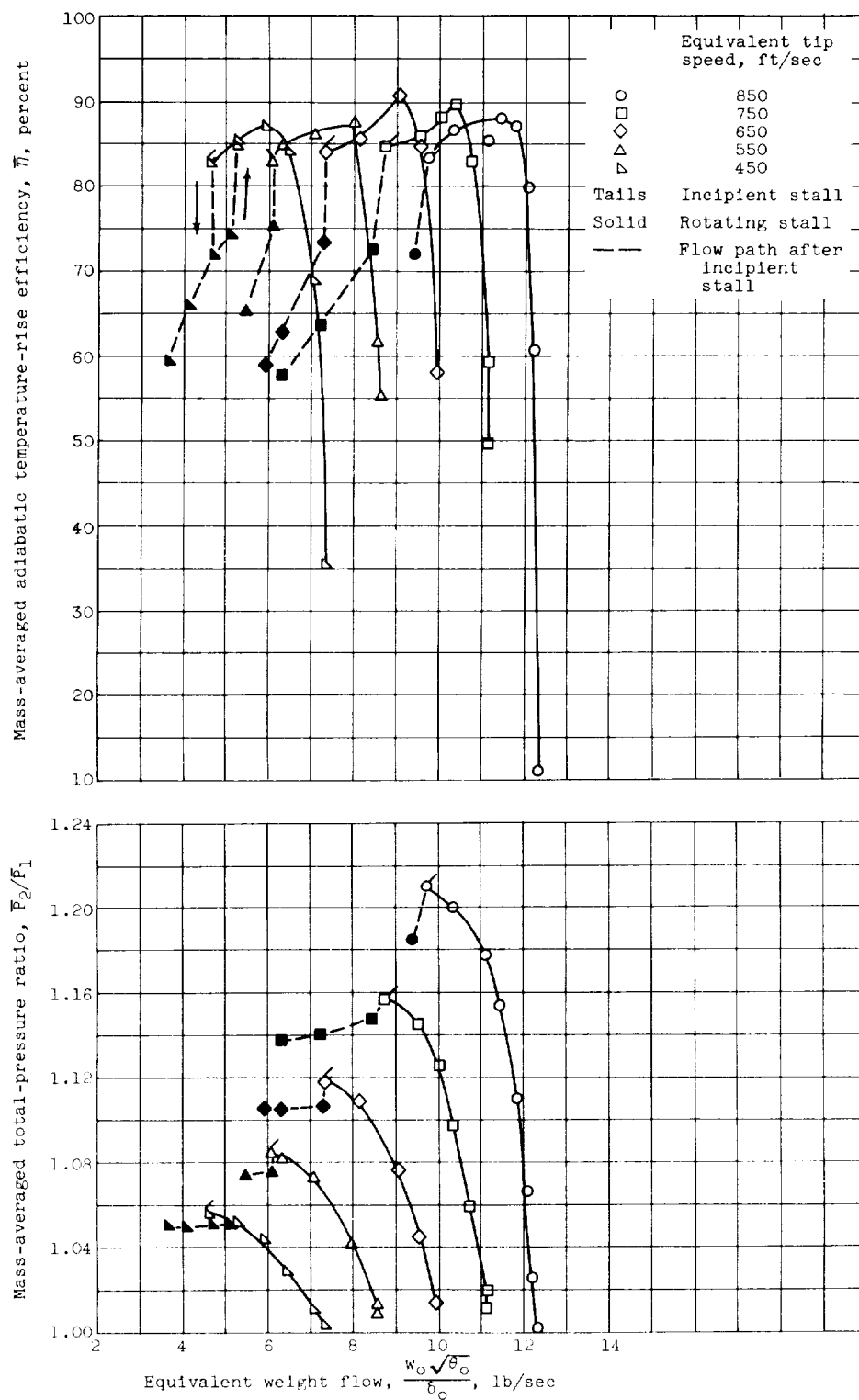


Figure 5. - Over-all performance of 58.7° setting blade row. Inlet pressure, 25 inches of mercury absolute.

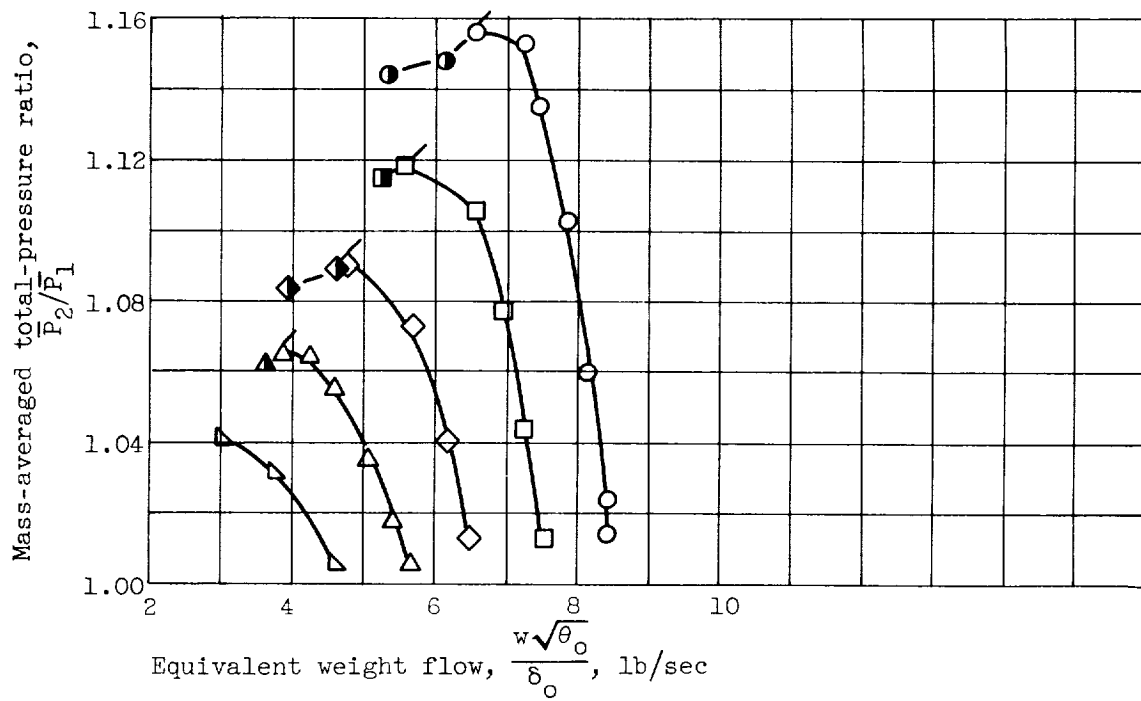
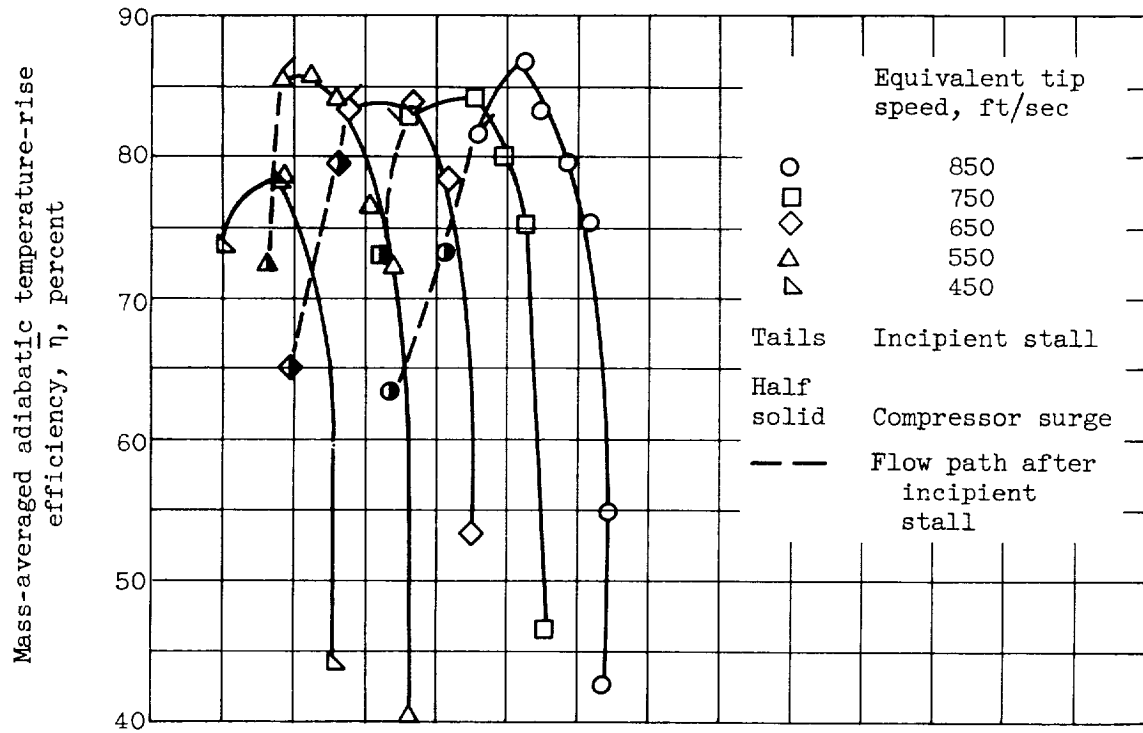


Figure 6. - Over-all performance of 68.7° setting blade row. Inlet pressure, 25 inches of mercury absolute.

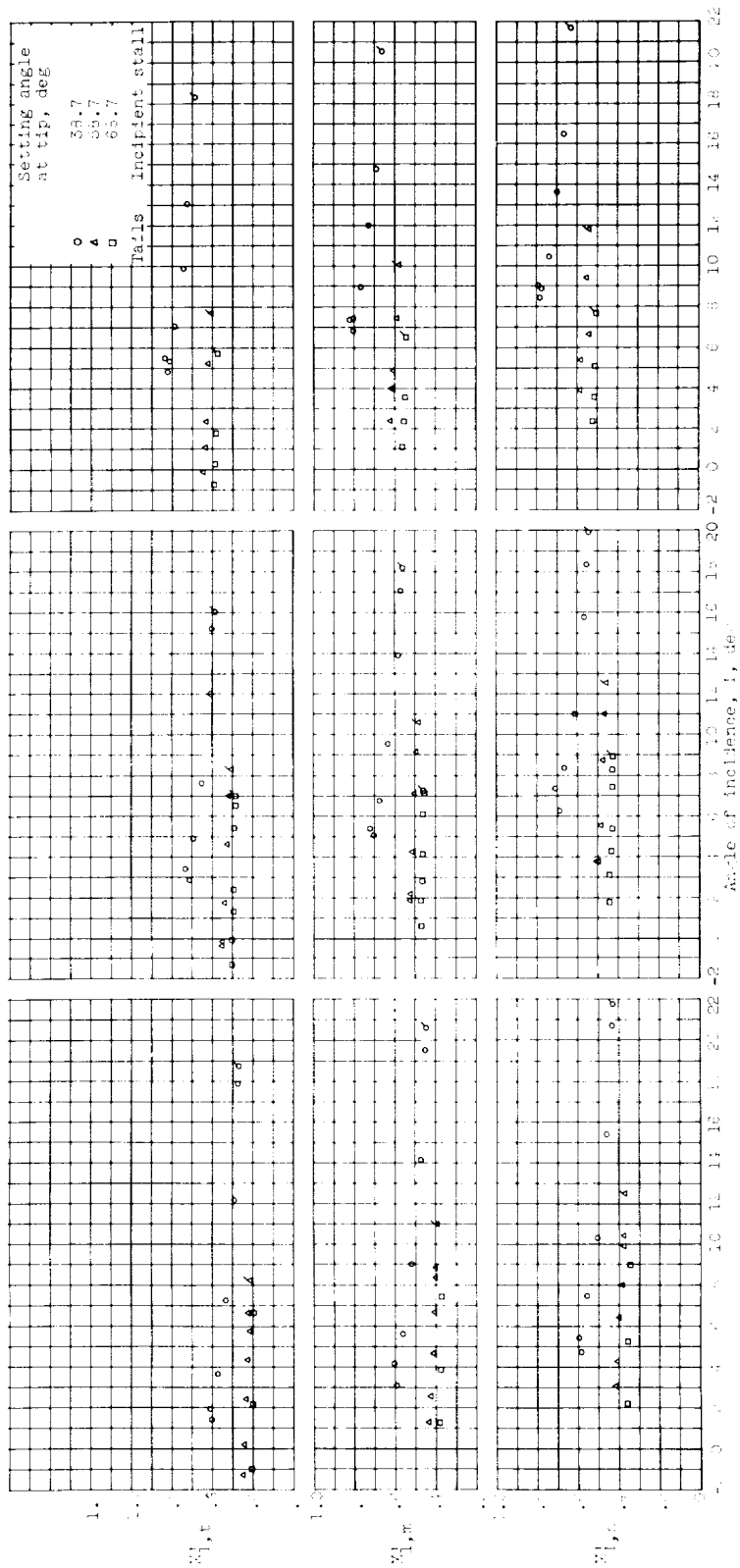
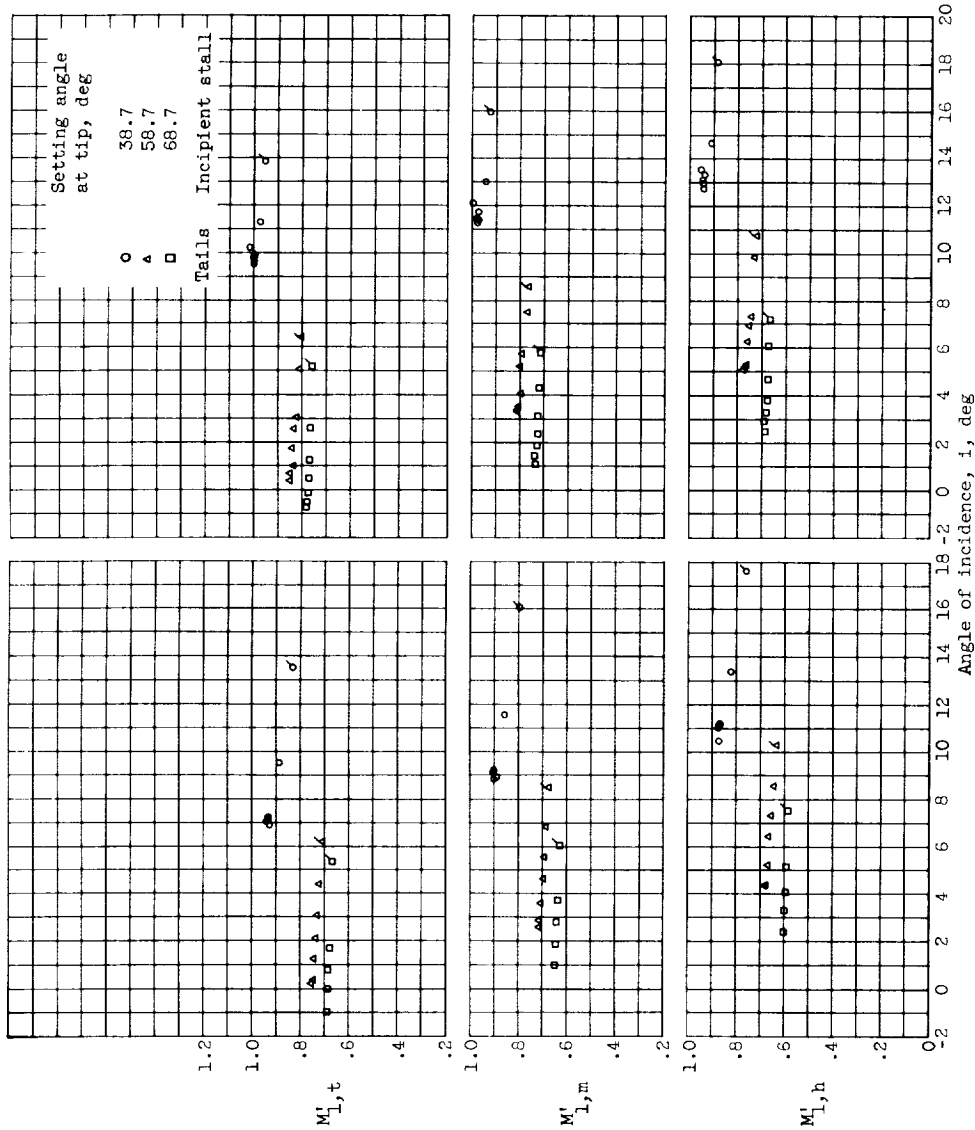


Figure 1. - Blade-element data for relative inlet Mach number, M_1 , for three blade setting angles at various equivalent tip speeds.



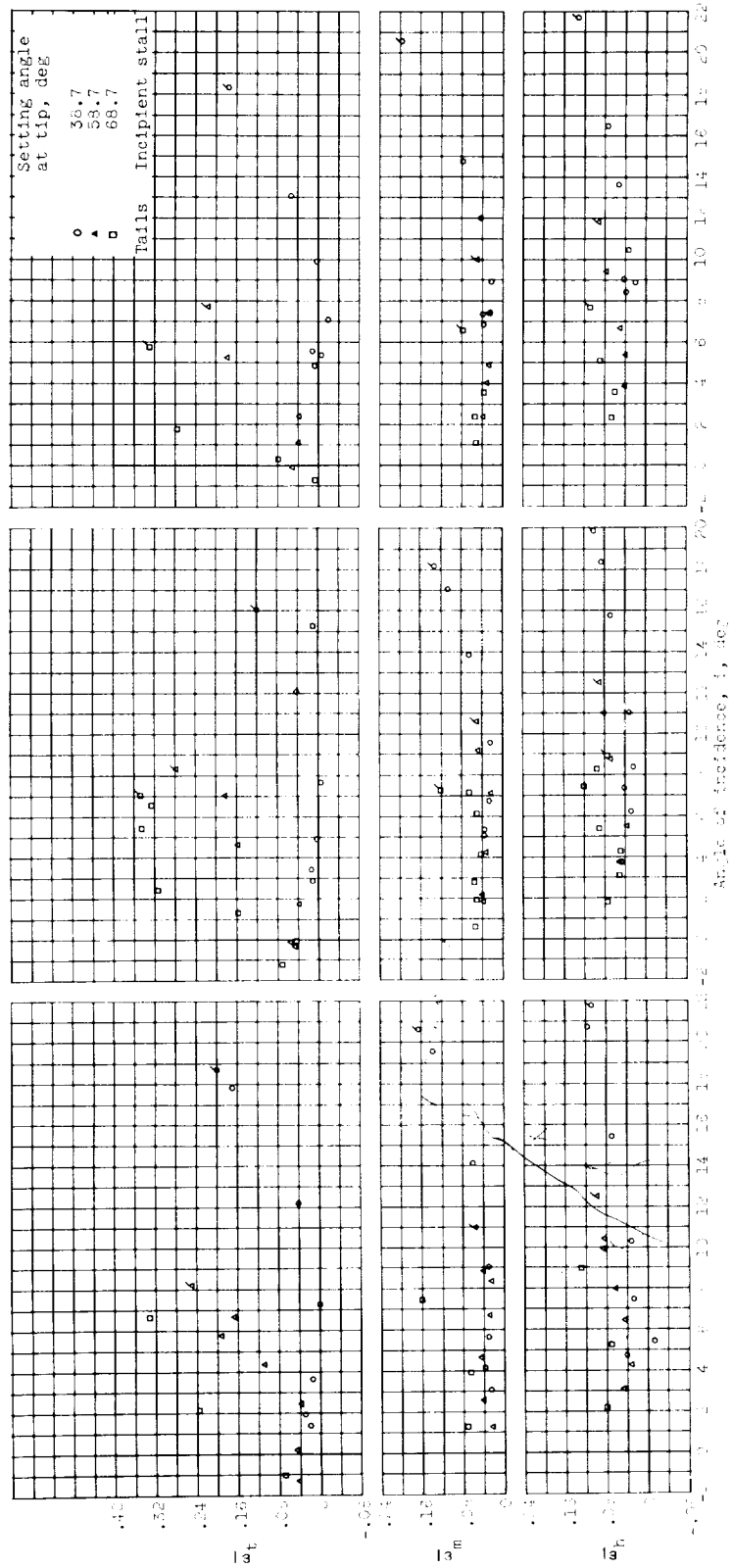


Figure 4. - Blade-element data for total-pressure-loss coefficient, \bar{w} , for three blade setting angles at various equivalent tip speeds.

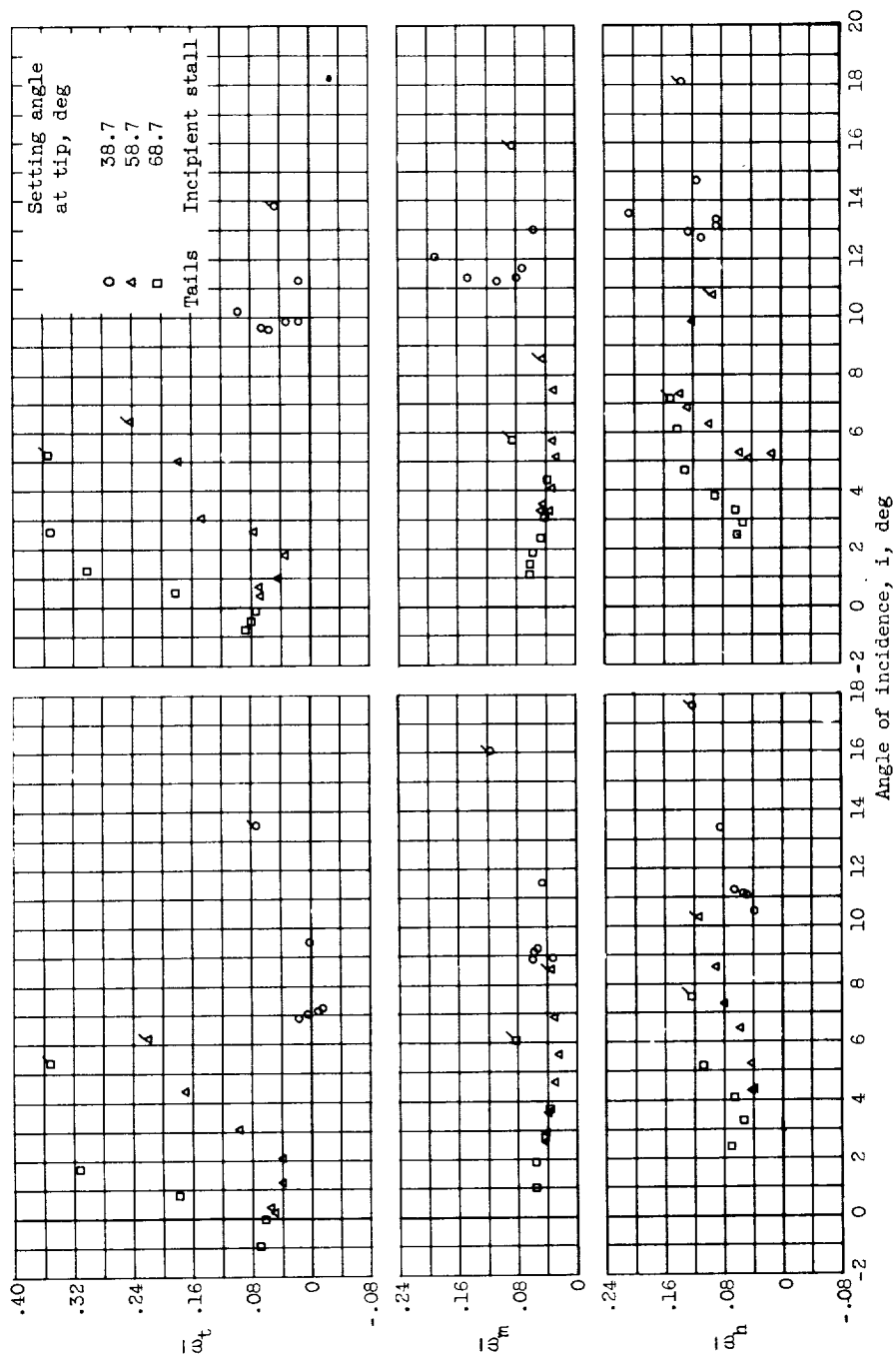


Figure 8. - Concluded. Blade-element data for total-pressure-loss coefficient, \bar{w} , for three blade setting angles at various equivalent tip speeds.

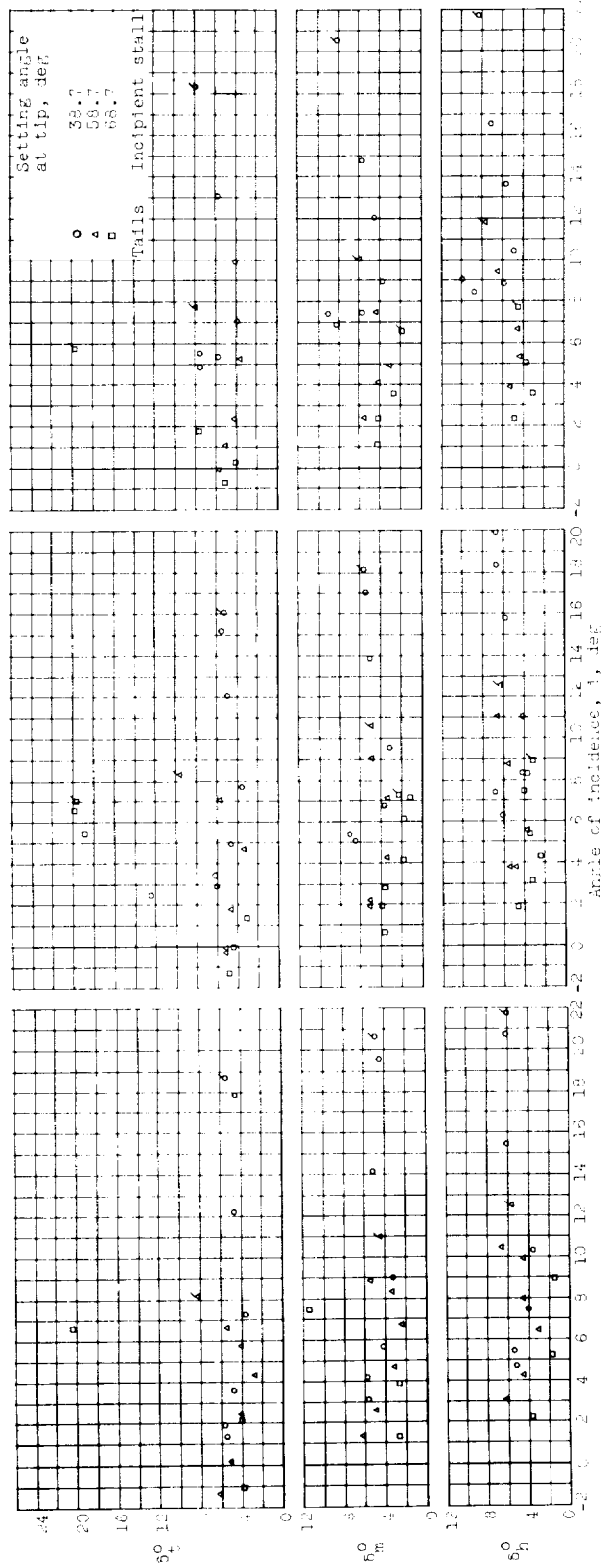
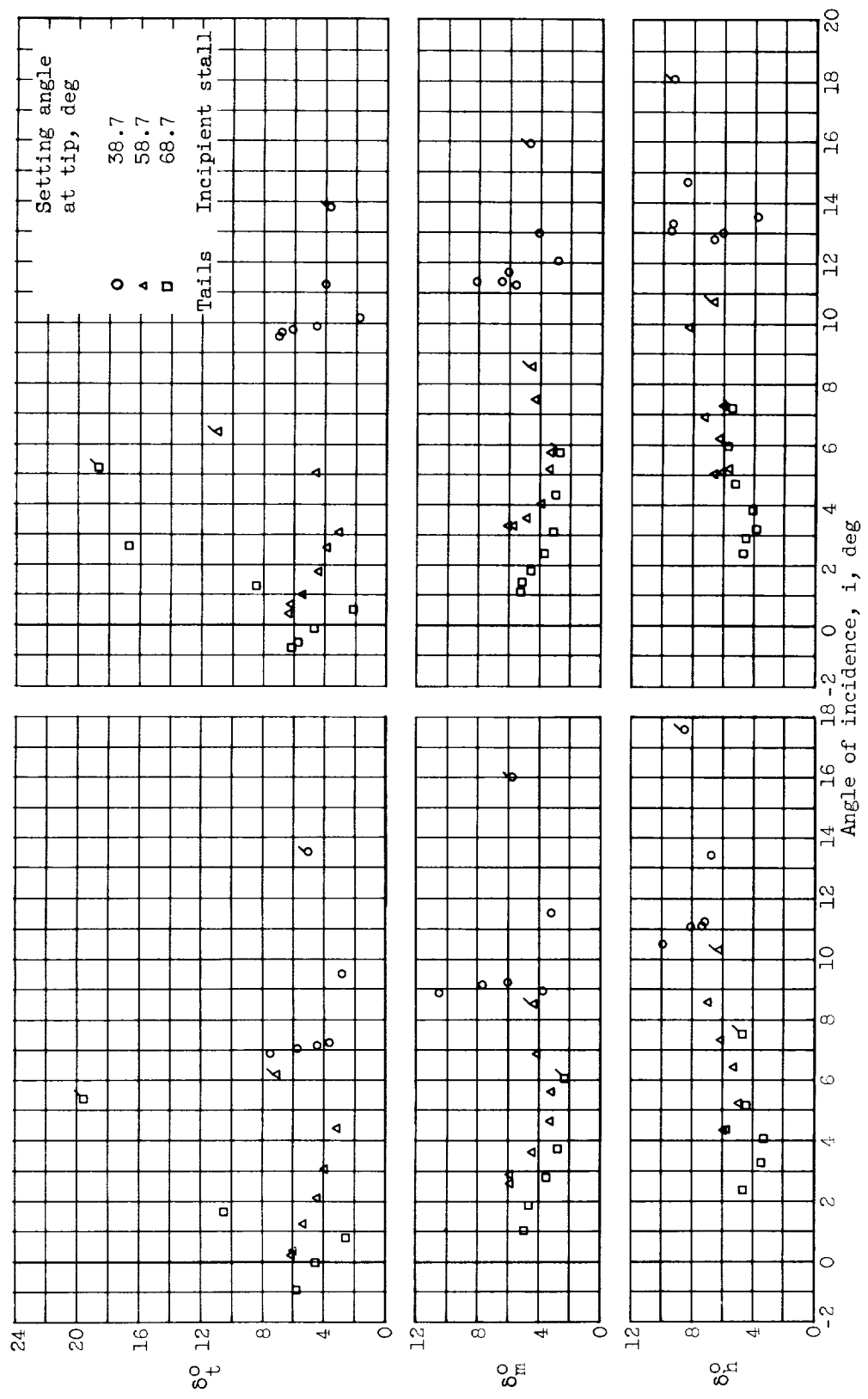
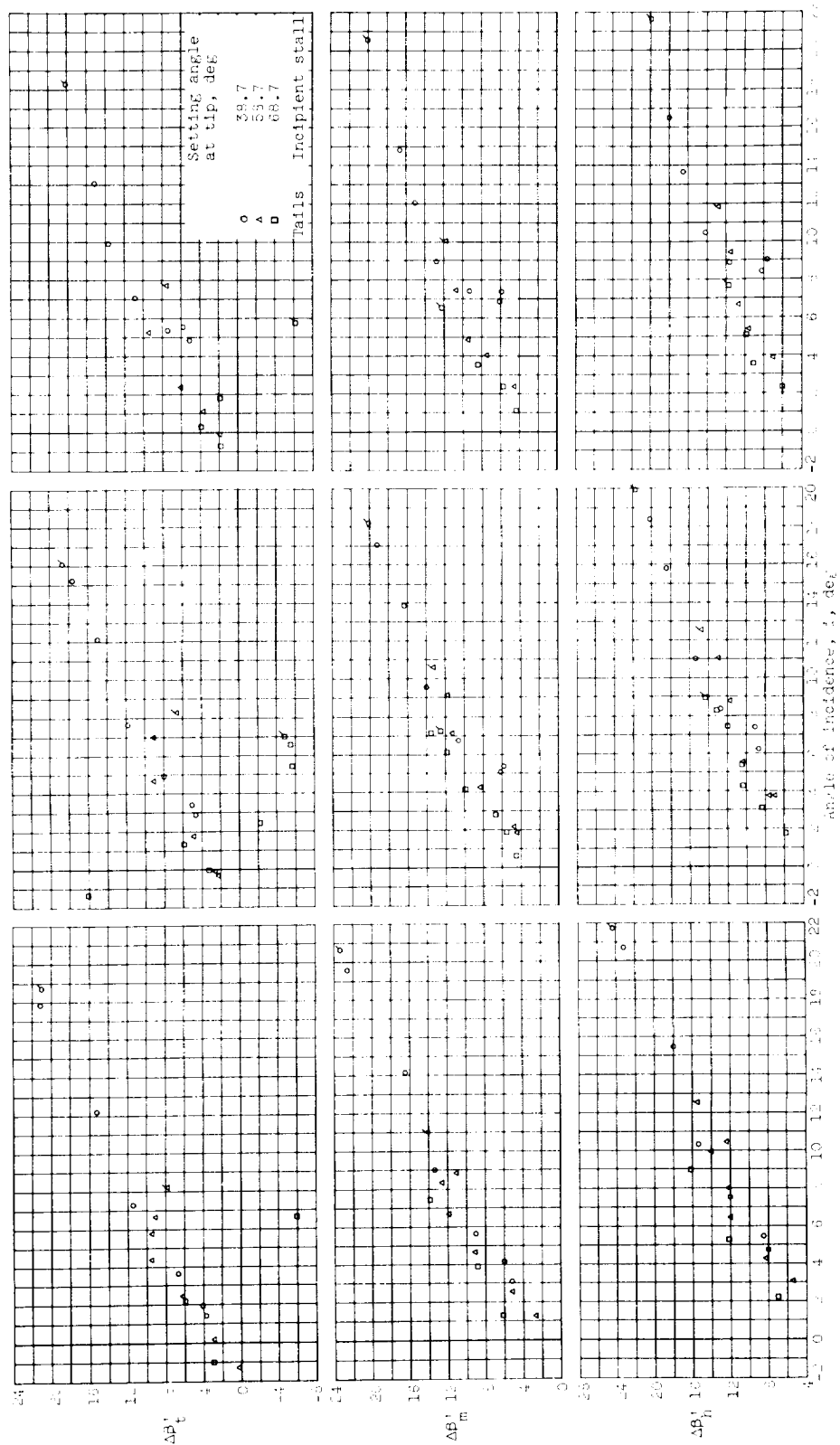


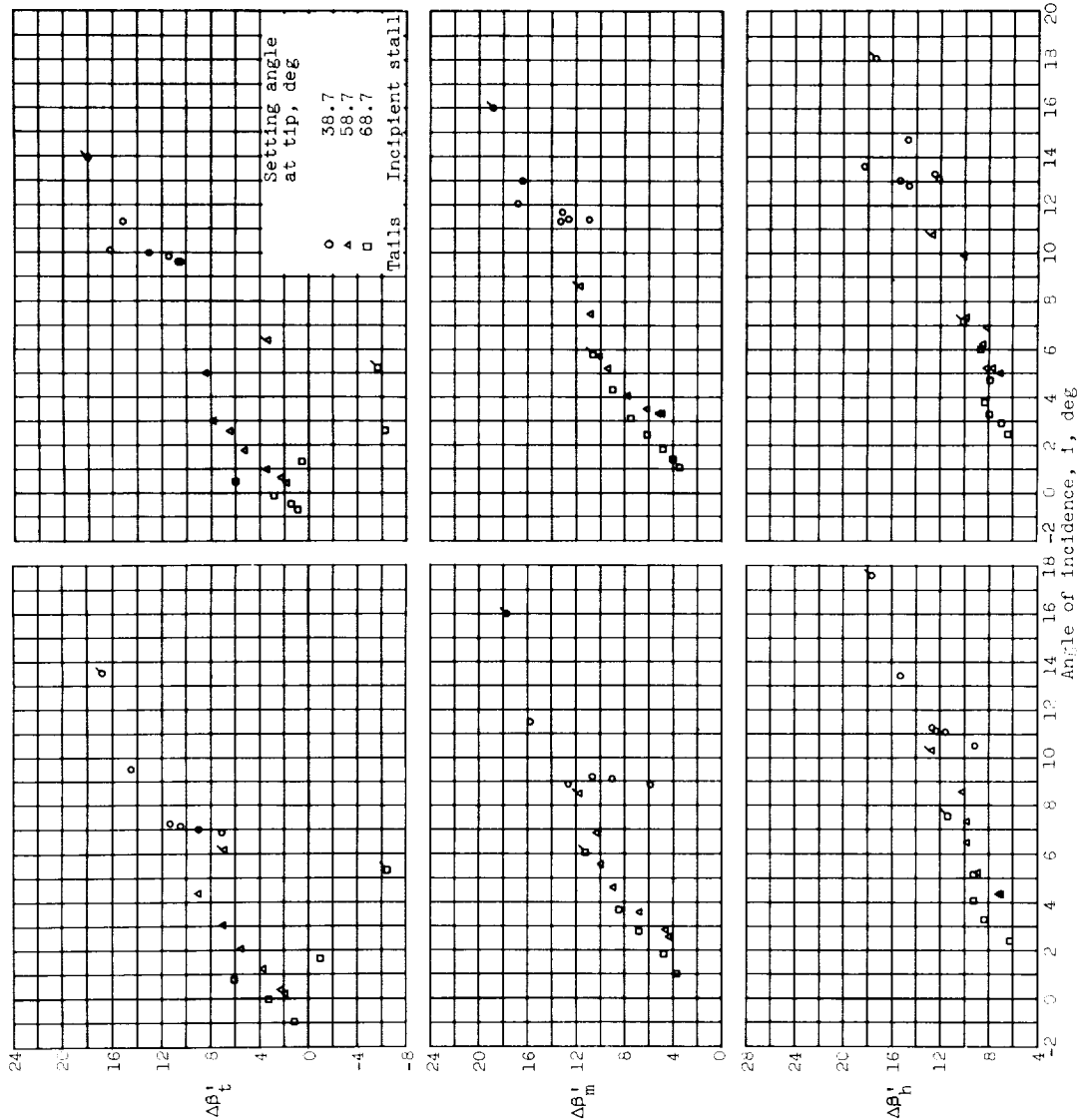
Figure 9. - Blade-element data for deviation angle, δ , for three blade setting angles at various equivalent tip speeds.



(d) Speed, 750 feet per second. (e) Speed, 850 feet per second.

Figure 9. - Concluded. Blade-element data for deviation angle, δ° , for three blade setting angles at various equivalent tip speeds.





(d) Speed, 750 feet per second. (e) Speed, 850 feet per second.
 Figure 10. - Concluded. Blade-element data for turning angle, $\Delta\beta'$, for three blade setting angles at various equivalent tip speeds.

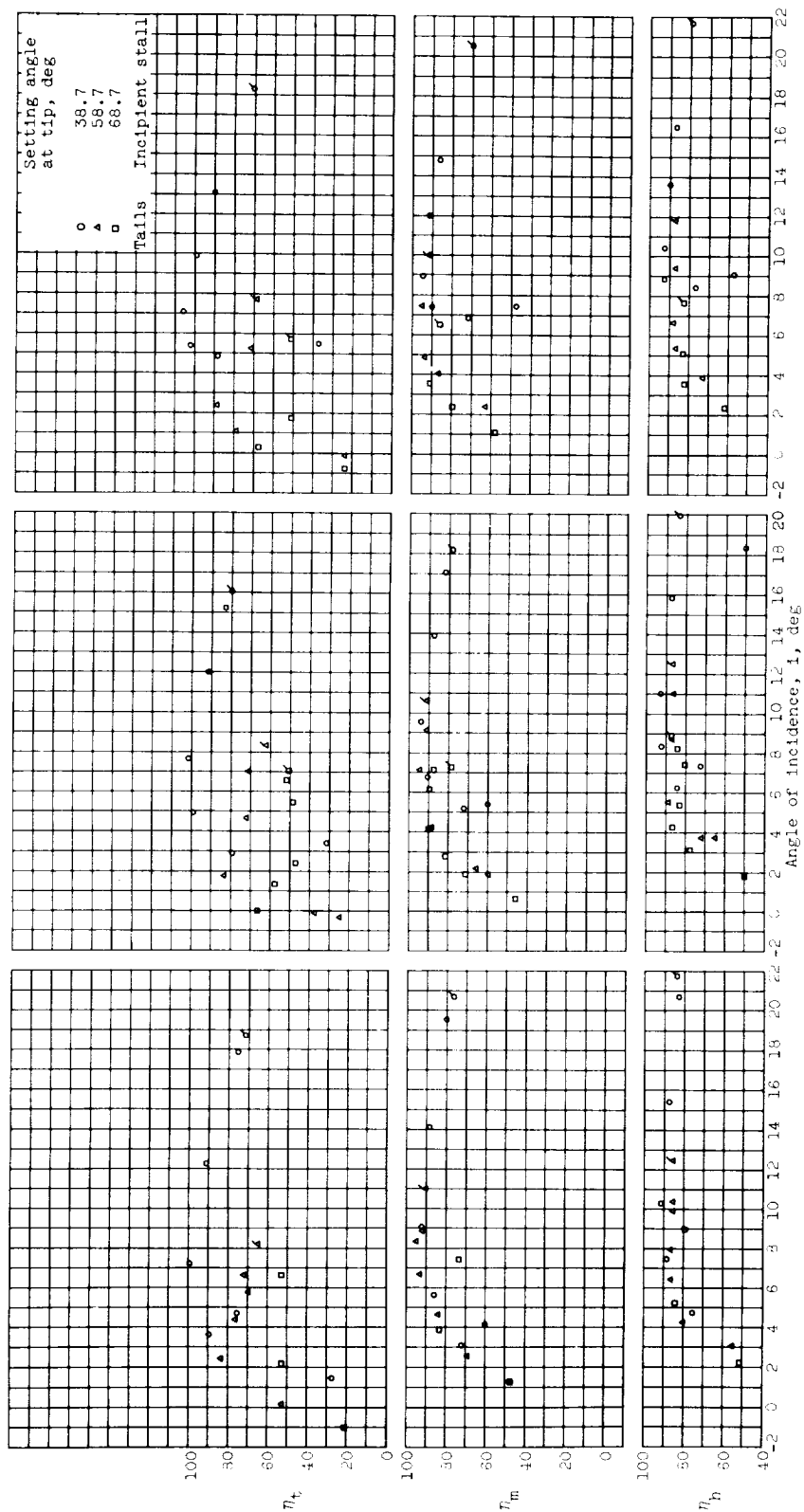
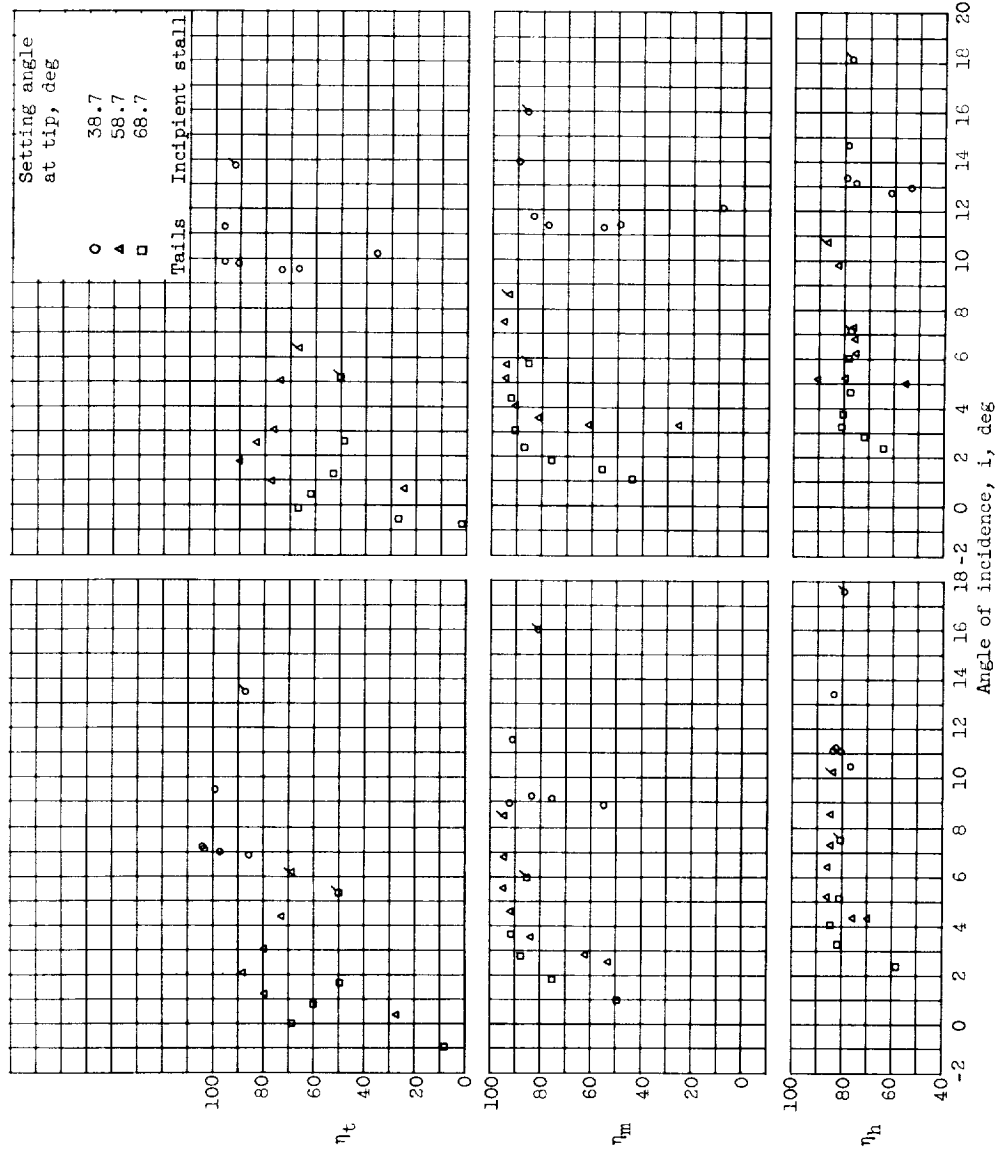


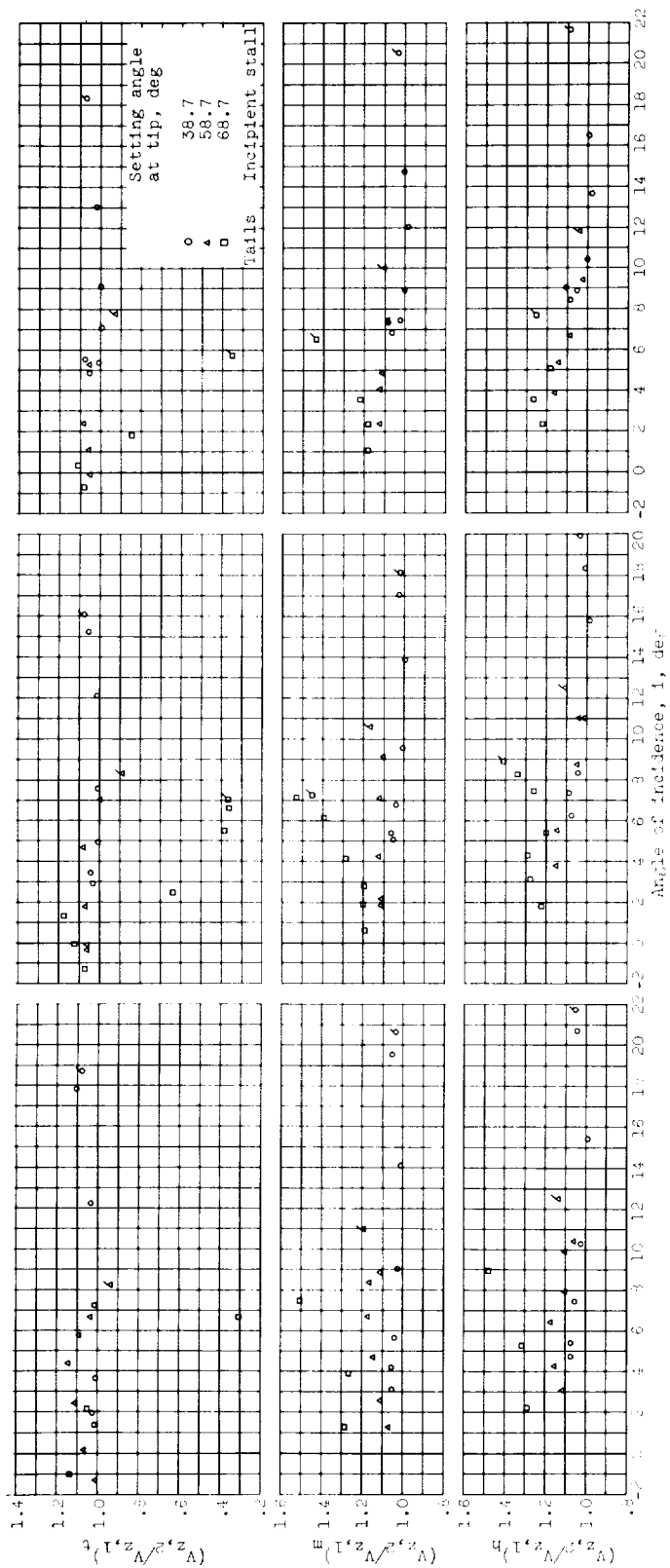
Figure 11. - Blade-element data for adiabatic temperature-rise efficiency, η , for three blade setting angles at various equivalent tip speeds.



(d) Speed, 750 feet per second.

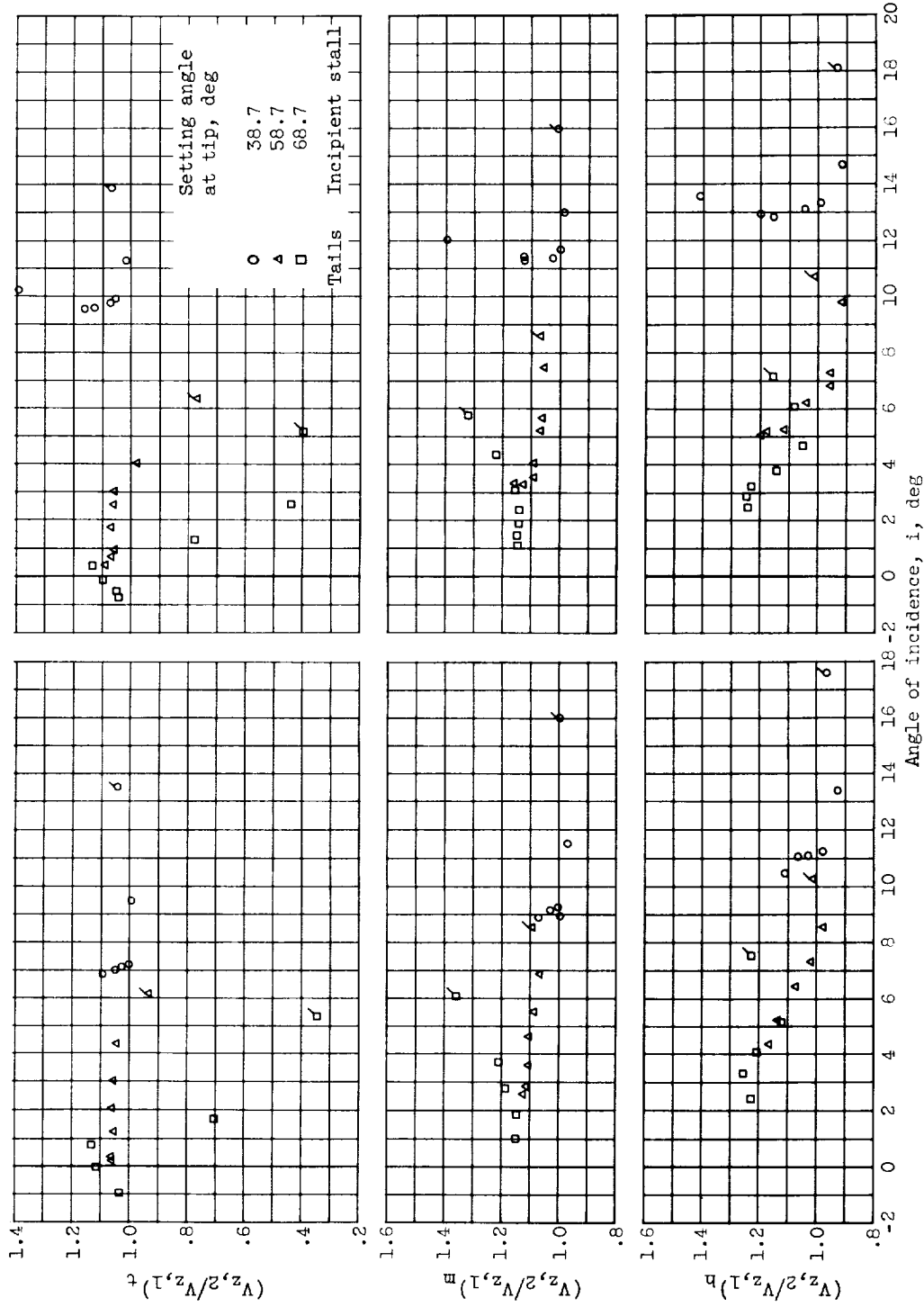
(e) Speed, 850 feet per second.

Figure 11. - Concluded. Blade-element data for adiabatic temperature-rise efficiency, η , for three blade setting angles at various equivalent tip speeds.



(a) Speed, 150 feet per second. (b) Speed, 650 feet per second. (c) Speed, 650 feet per second.

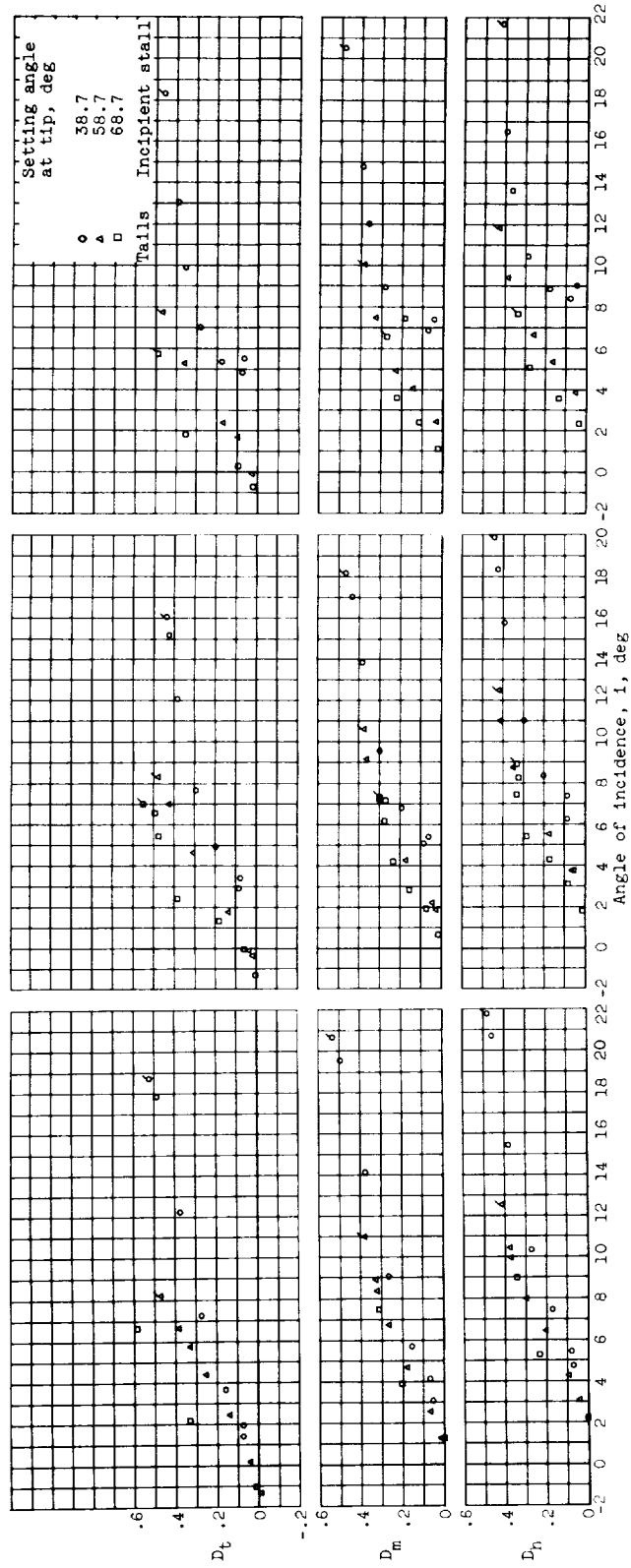
Figure 12. - Blade-element data for axial velocity ratio, $V_z/V_{z,1}$, for three blade setting angles at various equivalent tip speeds.

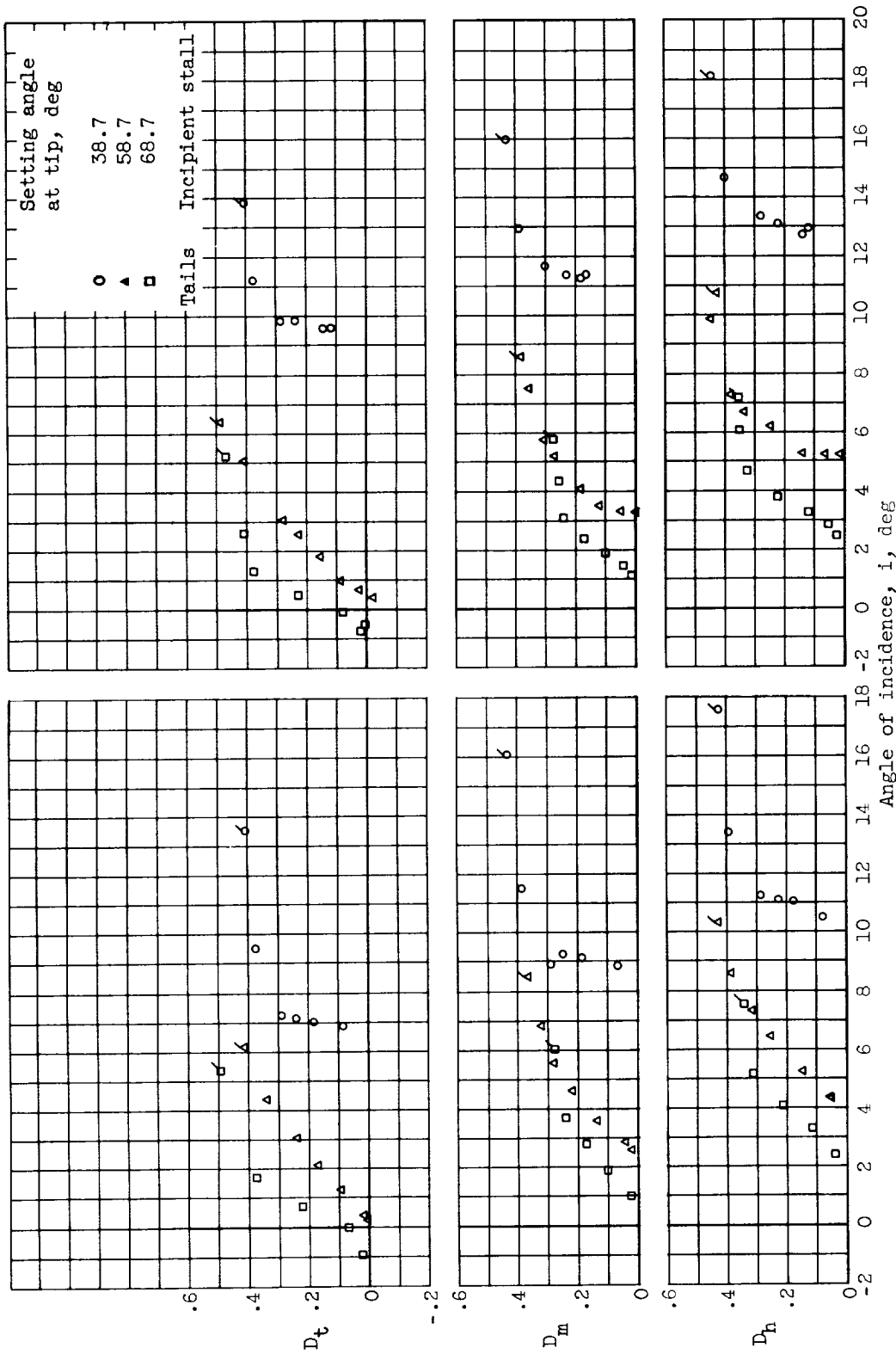


(d) Speed, 750 feet per second.

(e) Speed, 850 feet per second.

Figure 12. - Concluded. Blade-element data for axial velocity ratio, $V_{z,2}/V_{z,1}$, for three blade setting angles at various equivalent tip speeds.





(d) Speed, 750 feet per second.

(e) Speed, 850 feet per second.

Figure 13. - Concluded. Blade-element data for diffusion factor, D, for three blade setting angles at various equivalent tip speeds.

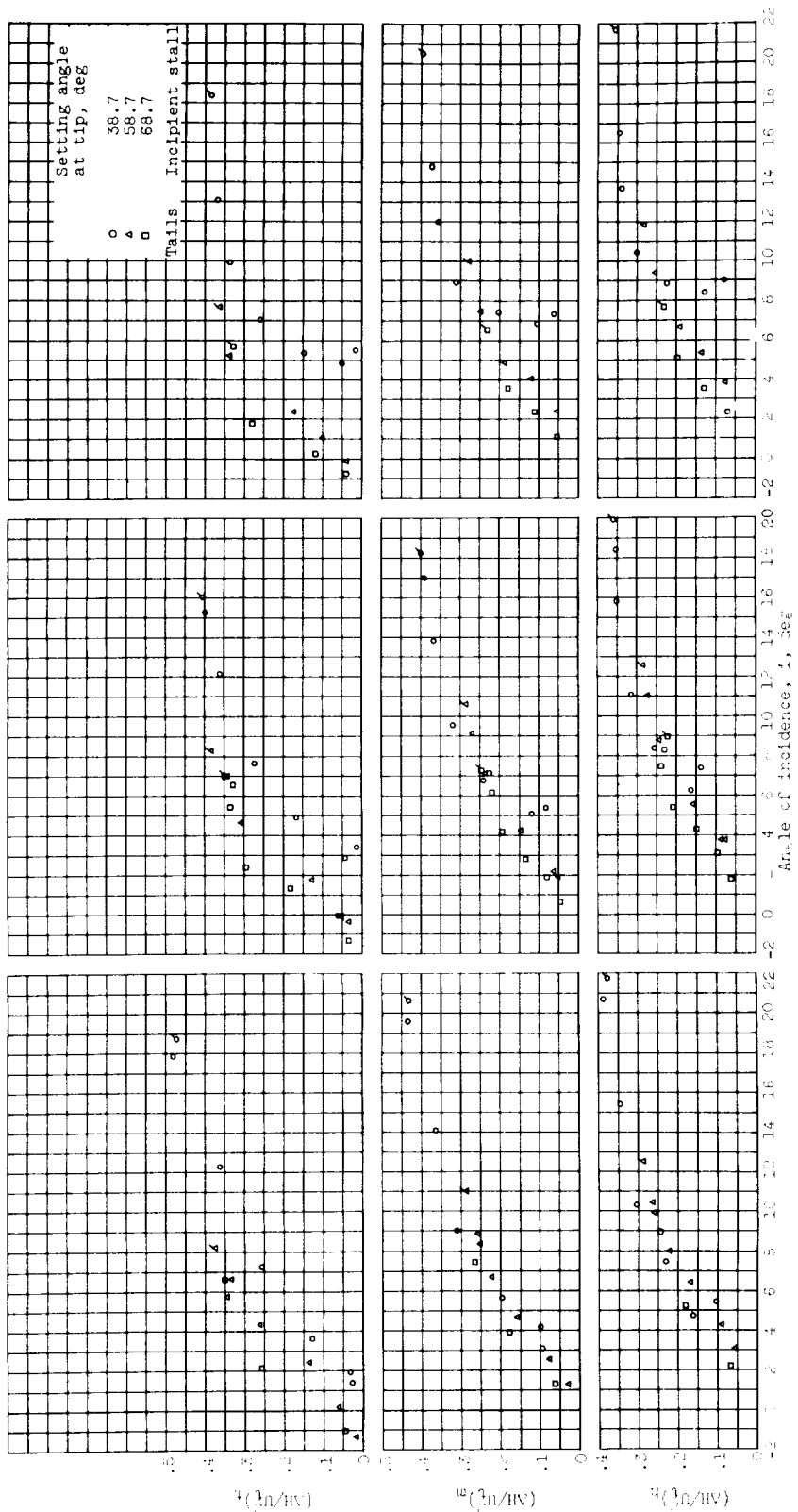
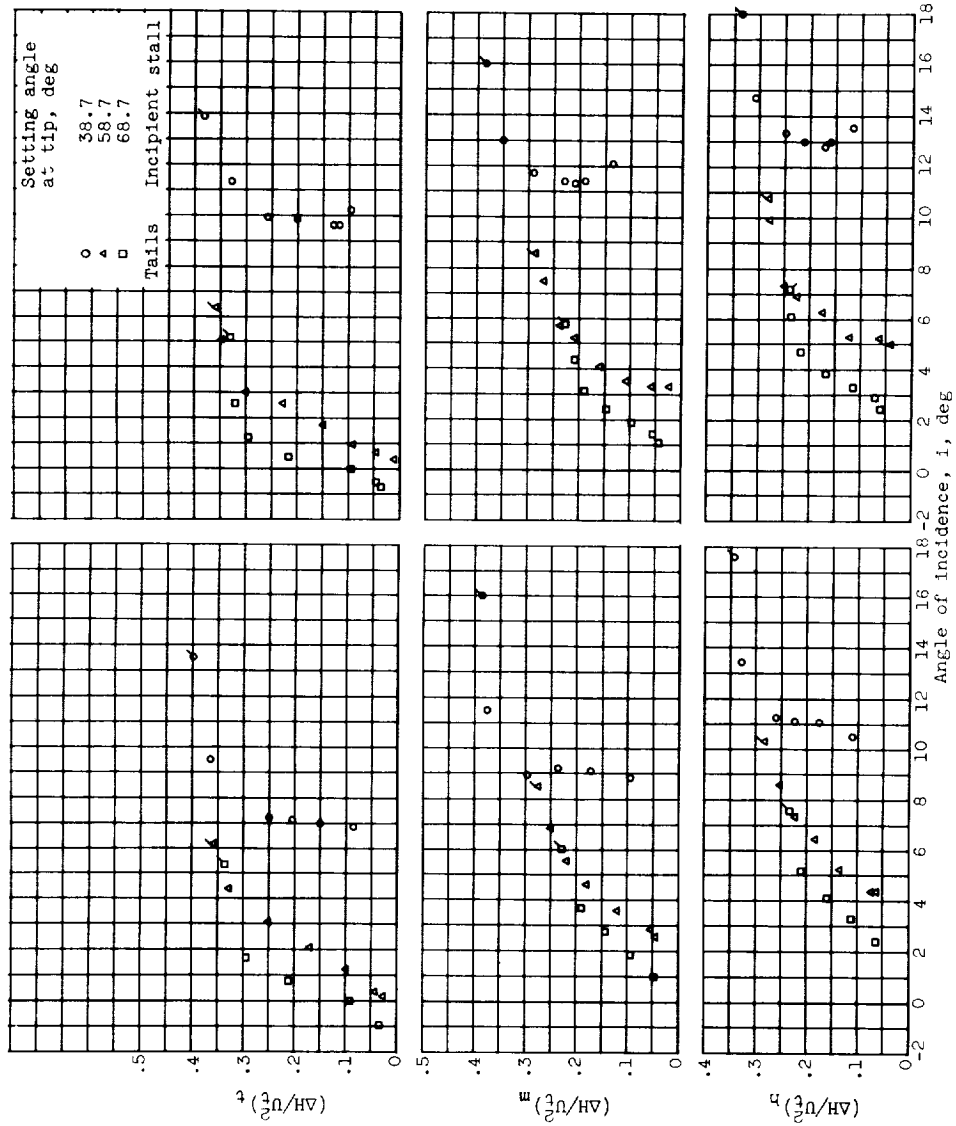


Figure 14. - Blade-element data for work coefficient, $\Delta H/U_t^2$, for three blade setting angles at various equivalent tip speeds.



E-117

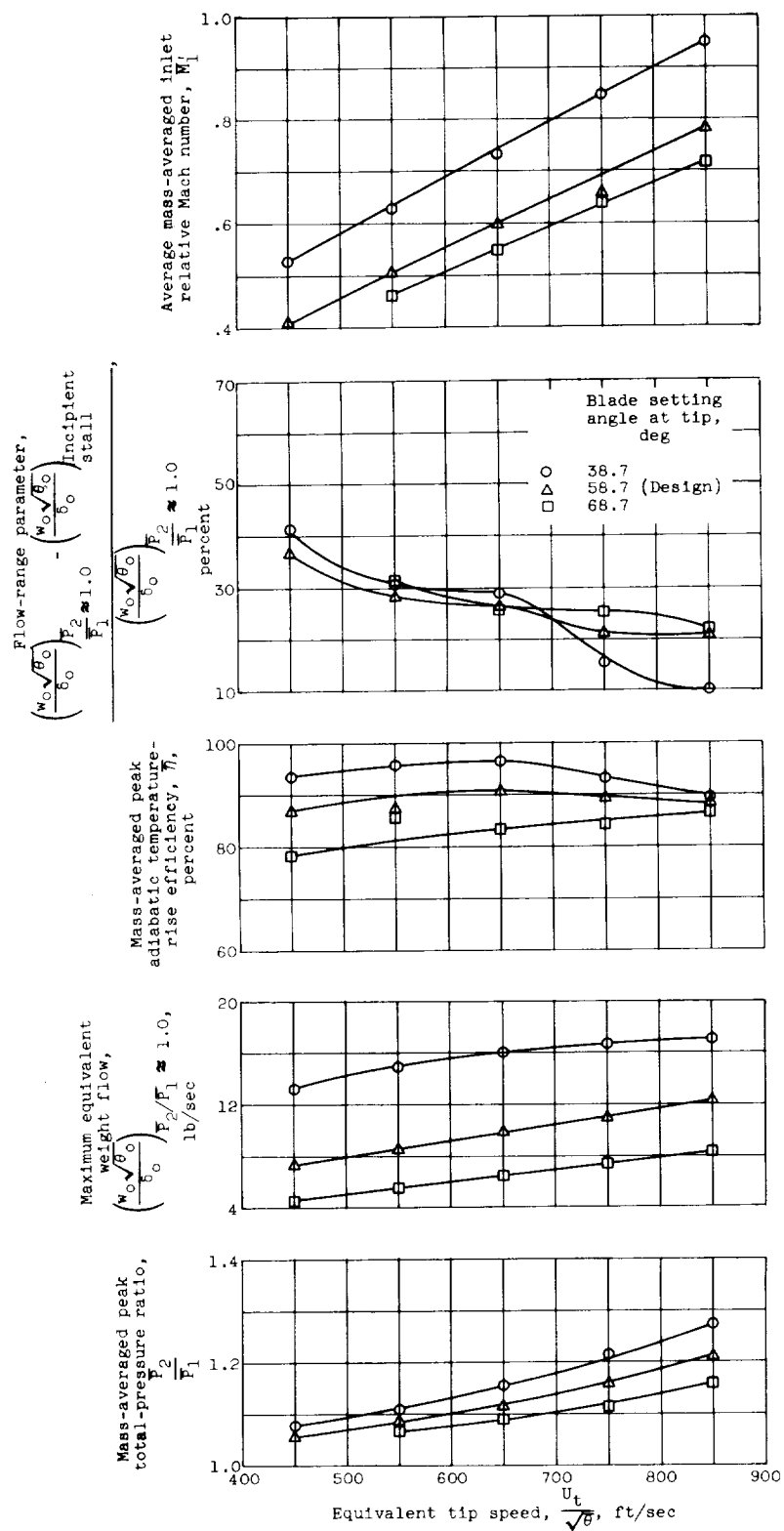


Figure 15. - Compressor performance at blade setting angles of 38.7°, 58.7°, and 68.7°.

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| <p>NASA MEMO 11-27-58E National Aeronautics and Space Administration. PERFORMANCE OF TYPICAL REAR-STAGE AXIAL-FLOW COMPRESSOR ROTOR BLADE ROW AT THREE DIFFERENT BLADE SETTING ANGLES. Marvin I. Kussoy and Daniel Bachkin. January 1959. 37p. diagrs., photo., tabs. (NASA MEMORANDUM 11-27-58E)</p> <p>A comparison of the performance of a single-stage rotor run at three setting angles covering a 30° range is presented. The results indicate higher peak pressure ratios and greater maximum equivalent weight flows for the lower setting angles at all speeds tested. During part-speed operation, the efficiencies were higher for the lower setting angles and the flow ranges were about the same for all three setting angles. However, near maximum speed, the flow range was noticeably less for the lowest setting angle while the efficiencies were about the same for each configuration.</p> <p>Copies obtainable from NASA, Washington</p> | <p>1. Compressors - Axial-Flow (3.6.1.1) I. Kussoy, Marvin I. II. Bachkin, Daniel III. NASA MEMO 11-27-58E</p> <p>NASA</p> | <p>NASA MEMO 11-27-58E National Aeronautics and Space Administration. PERFORMANCE OF TYPICAL REAR-STAGE AXIAL-FLOW COMPRESSOR ROTOR BLADE ROW AT THREE DIFFERENT BLADE SETTING ANGLES. Marvin I. Kussoy and Daniel Bachkin. January 1959. 37p. diagrs., photo., tabs. (NASA MEMORANDUM 11-27-58E)</p> <p>A comparison of the performance of a single-stage rotor run at three setting angles covering a 30° range is presented. The results indicate higher peak pressure ratios and greater maximum equivalent weight flows for the lower setting angles at all speeds tested. During part-speed operation, the efficiencies were higher for the lower setting angles and the flow ranges were about the same for all three setting angles. However, near maximum speed, the flow range was noticeably less for the lowest setting angle while the efficiencies were about the same for each configuration.</p> <p>Copies obtainable from NASA, Washington</p> | <p>1. Compressors - Axial-Flow (3.6.1.1) I. Kussoy, Marvin I. II. Bachkin, Daniel III. NASA MEMO 11-27-58E</p> <p>NASA</p> |
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